Institute of
International
Agriculture

USAID

ABSP

# An Inventory of Agricultural Biotechnology for the Eastern and Central Africa Region

*Prepared for ASARECA and the Africa Bureau of the United States Agency for International Development*

*March 2001*

**Andrea Johanson and Catherine L. Ives**
Agricultural Biotechnology Support Project (ABSP)
Michigan State University

MICHIGAN STATE
UNIVERSITY

**Andrea Johanson and Catherine L. Ives**
Agricultural Biotechnology Support Project (ABSP)
Institute of International Agriculture
CANR Office of International Programs
319 Agriculture Hall, Michigan State University
East Lansing, Michigan 48824 USA
Phone: 517-432-1639 Fax: 517-432-1888
Email: absp@pilot.msu.edu
Website: http://www.iia.msu.edu/absp

*This publication was made possible through support provided by the Center for Economic Growth and Agricultural Development, Office of Agriculture and Food Security, Bureau for Global Programs, Field Support & Research, (G/EGAD/FAS) U.S. Agency for International Development, under the terms of Award No. DAN-A-00-91-00126-00. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of the U.S. Agency for International Development.*

# Inventory of Agricultural Biotechnology for the Eastern and Central Africa Region

## Table of Contents

# Inventory of Agricultural Biotechnology for the Eastern and Central Africa Region

## Introduction

### Objective

This report aims to examine the current status of agricultural biotechnology for priority crops in the Eastern and Central Africa region, We have focused on countries belonging to The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), namely Burundi, Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda, but much of the content will be applicable to other countries in Africa, and to other developing countries outside of the continent.

The report is in no way exhaustive. Progress in the field of agricultural biotechnology is very rapid, and there may be work in both the public and private sectors that is unpublished and/or unreported. However, we hope that the main areas of progress in the major crops are covered fully enough to reflect the scope of current work, and more importantly, the future potential of biotechnology tools for improving crops that are of importance to Africa.

This report follows on from an earlier document, Considering Biosafety and Biotechnology from an ASARECA Perspective: Assessing the Feasibility of a Regional Initiative on Biotechnology for Agricultural Research in Eastern and Central Africa, a study by The International Service for National Agricultural Research (ISNAR). That study was commissioned by ASARECA and funded by the United Nations Development Program (UNDP) and the U.S. Agency for International Development's Agricultural Biotechnology Support Project (ABSP) at Michigan State University.

### Organization of the report

First, we will discuss the scope of this report, then give a brief background of the techniques of agricultural biotechnology and their potential with particular reference to African agricultural systems. The bulk of the report will focus on the current developments in biotechnology for specific priority crops in the ASARECA region, giving a list of currently available transgenic varieties of each crop and a brief discussion of the potential of biotechnology for addressing the specific production constraints of that crop.

## Scope of the report

In many ways agricultural biotechnology is still in its infancy. But from some of the achievements that have already been made, we can envisage the possible future advances when currently available technology is applied to crop varieties of importance to Africa. Much of the preparatory work has already been done in the developed world by the public and private sector, and now the benefits of this basic work can be adapted and applied to crops that are a priority in African agricultural systems.

It is important to note that this report does not analyze the availability of any one technology vis-à-vis intellectual property rights (IPR). Any use of a particular technology will always require an analysis of its IPR status and potential negotiations with the owners of the technology. Additionally, this report does not discuss regulatory issues surrounding the implementation of biotechnology-derived products (e.g., “biosafety”).

Ives and Wambugu (1999) clearly state that African policymakers and scientists will need to understand the IPR issues in order to access technologies both from private and public institutions. As with any industry, collaborations with advanced laboratories in the public sector in biotechnology will also require negotiations. This does not mean that technology cannot be accessed, but that arrangements must be formalized with legal agreements to ensure the proper transfer of research tools, collaborations and materials.

In both developing and developed countries, the safe application of biotechnology to problems of agricultural productivity requires an appropriate biosafety system that encompasses both policy and regulations. Companies or collaborative research programs seeking to produce genetically engineered crops for developing country needs are reluctant to operate in the absence of a regulatory structure. A well-designed biosafety policy will ensure the safety of human health and the environment without stifling innovation or product development. Biosafety policy should be integrated with national policies in agriculture, food safety and environmental protection, and establish the scope of guidelines or regulations. Those regulations should address relevant scientific and technical issues and describe procedures for safe handling of genetically engineered material in the laboratory, greenhouse and field. Developing a regional approach to biosafety regulatory systems that allows individual countries to retain the right to make the final decision has been proposed for Africa.

As can be seen from the lists of transgenic crops in this report, products developed using the tools of modern biotechnology are now commercially available in a number of countries around the world. Because of the nature of the industry thus far, many of the commercially available transgenic crops listed were developed to perform well in the more developed regions of the world, particularly northern Europe and North America. Many will therefore not be appropriate for Africa, but some, e.g., some of the insect-resistant maize and cottons, may be. Others will have traits that may be applicable in Africa, but in a genetic background that is not adapted to local growing conditions, or in a variety that would not suit local taste preferences. In such cases adaptive research is needed to insert the desired trait into local adapted and improved varieties, or indeed into other crops where the trait might be of value. However, some of the commercially available traits may not be seen as a priority in the developing world (e.g., the development of potatoes with different starches that absorb less fat in frying may not be as high a priority in Africa as in the developed world).

In this report we have focused primarily on the ASARECA priority crops, but we have also included related advances in some other regionally important crops.

## Background

Worldwide, the beneficial economic impact of plant biotechnology has so far been almost exclusively on crops of high economic importance in developed countries, such as maize, canola, soybean, and potato. Other species, although important to the developing countries of Africa, have not attracted the interest of the multinational seed and biotechnology companies, primarily for financial reasons. Commercialized world crops are not as important in Africa, since most imported lines or cultivars may be inappropriate for local conditions. These crops varieties may be expensive and need high inputs, and may also be susceptible to local pests and diseases. As a result, genetic and biotechnological improvements to these "neglected" food species are confined to local and specialized research at specific crop centers within the international agricultural research centers in those countries, and/or in specific collaborations with agricultural research institutes (ARIs) in industrialized countries. However, African biotechnological expertise is being nurtured through several recent international initiatives (see list in Brink *et al*., 1998).

### *The potential of agricultural biotechnology*

Between 1996 and 1998, eight countries, five industrial and three developing, have contributed to more than a 15-fold increase in the global area of transgenic crops (James, 1999). In 1998, that area increased to 27.8 million hectares from 11.0 million hectares in 1997. Only five major crops planted in just eight countries account for most of this increase. The five principal transgenic crops are (in decreasing order of area) soybean, maize, cotton, canola/rapeseed, and potato (Table 2). Transgenic soybean alone makes up over 50% of this acreage. The most common transgenic trait is herbicide resistance (71%), followed by insect resistance (28%) (Table 3). In 1998, the United States had the greatest percentage of the global area of transgenic crops (74%), followed by Canada (19%), Argentina (15%), Australia (1%), Mexico (<1%), Spain (<1%) and France (<1%) (Table 1).

**Table 1. Global area of transgenic crops by country in 2000 (from James, 2000)**

| Country | Area (million hectares) |
|---|---|
| USA | 30.3 |
| Argentina | 10.0 |
| Canada | 3.0 |
| China | 0.5 |
| Australia | 0.2 |
| South Africa | 0.2 |
| Mexico | <0.1 |
| Spain | <0.1 |
| France | <0.1 |
| Bulgaria | <0.1 |
| Romania | <0.1 |
| Uruguay | <0.1 |
| Germany | <0.1 |

**Table 2. Global area of transgenic crops by crop in 2000 (James, 2000)**

| Crop | Area (million hectares) |
|---|---|
| Soybean | 25.8 |
| Maize | 10.3 |
| Cotton | 5.3 |
| Canola | 2.8 |
| Potato | <0.1 |
| Squash | <0.1 |
| Papaya | <0.1 |

**Table 3. Global area of transgenic crops by trait in 2000 (James, 2000)**

| Trait | Area (million hectares) |
|---|---|
| Herbicide tolerance | 32.7 |
| Insect resistance (Bt) | 8.3 |
| Bt & herbicide tolerance | 3.2 |
| Virus resistance/other | <0.1 |

The goals of agricultural biotechnology are essentially the same as those of conventional plant breeding, with one or two exceptions. In general terms these goals fall into two major categories: improving crop performance in the field (*input traits*), and developing new products with enhanced quality or value (*output traits*). So far, most commercially grown transgenic crops are those with input traits, but in the next few years we anticipate the commercial release of many more crops with output traits. Combined input and output goals include:

- ***increased resistance to pests and diseases – insects, viruses, fungi, nematodes, etc.;***
- ***increased tolerance of environmental stresses -- drought, flooding, soil acidity and alkalinity, heavy metals and extreme temperatures;***
- ***increased yield;***
- ***reduced post-harvest losses;***
- ***improved nutritional content of foods and feedstuffs.***

A combination of conventional breeding and biotechnology means that genes introduced into one variety by genetic modification can often be moved into ”elite” varieties (highly productive, commercially successful varieties), or locally adapted varieties within economically viable timeframes.

*One of the major advantages of plant biotechnology is that it can generate strategies for crop improvement that can be applied across many different crops*. Genetically engineered virus resistance, insect resistance, and delayed ripening are good examples. Transgenic plants of over 20 plant species that are resistant to more than 30 different viral diseases have already been produced by using different variations of the pathogen-derived resistance strategy. Insect-resistant plant varieties, using the $\delta$-endotoxin of *Bacillus thuringiensis*, have been produced for several important plant species, including tobacco, tomato, potato, cotton, walnut, maize, sugar cane and rice. Of these, maize, potato and cotton are already under commercial production. It is envisaged that these strategies will be equally applicable to many other crops important for developing countries. Genetically engineered delayed ripening, although tested so far on a commercial scale only for tomato, may also have an enormous potential application for tropical fruit crops that suffer severe losses because they ripen rapidly. In many developing countries with inadequate storage and transportation systems, delayed ripening for fruits could prove a significant factor in their efficient commercialization.

In a recent study commissioned by the Rockefeller Foundation (*Biotechnology for African Crops,* 1999) the authors note that crop production in African countries is usually constrained by incidence of pest and disease, poor soil conditions, and abiotic stress factors such as drought and heat. These constraints are grouped into the following major categories:

- Propagation – lack of clean planting material
- General - technology development or germplasm conservation
- Disease - viral, fungal, bacterial

- Insect pests
- Weeds
- Abiotic stress - drought, heat, nitrogen deficiency
- Quality - yield or nutritional content

Most or all of these constraints may be addressed via biotechnological methods.

## *The tools of biotechnology*

Biotechnology is the name that has been given to a very wide range of agricultural, industrial and medical technologies that make use of living organisms (e.g., microbes, plants or animals) or parts of living organisms (e.g., isolated cells or proteins) to provide new products and services. Although the term biotechnology refers to a much older and broader technology than genetic engineering, the techniques of genetic engineering are of such importance that the two terms have become virtually synonymous.

Biotechnology can be defined as "making use of the natural processes or products of living things." Some forms of biotechnology, such as wine-, bread- and cheese-making, have been practiced for thousands of years. Biotechnology is used in many different ways, from sewage treatment to pharmaceutical manufacturing. The applications of biotechnology include:

- **medical biotechnology --** e.g., using microorganisms such as bacteria or fungi to make antibiotics or vaccines;

- **industrial biotechnology --** e.g., using microorganisms to make enzymes to add to biological washing powders, to produce beer or cheese or bread, or to make vitamins or calorie-free sweeteners;

- **environmental biotechnology --** e.g., using microorganisms or plants to clean up land or water polluted with sewage or toxic industrial waste (bioremediation).

Biotechnology does not necessarily involve transgenic technologies or genetic engineering per se, but these techniques can be used to make entirely new or improved products, often referred to as "*modern biotechnology*." Most of the current public concern is over modern biotechnology, because the use of genetic engineering allows the movement of genes in ways that could not have been easily accomplished previously (e.g., across species barriers). Less controversial biotechnology techniques commonly used in agriculture include tissue culture, genetic markers, and DNA-based diagnostics.

This report will focus primarily on transgenic technologies, although where these are less developed for a particular crop we will refer to other applications of molecular biology that are currently in use. A brief explanation of these techniques follows.

### Tissue culture

Plant tissue culture is the cultivation of plant cells or tissues on specially formulated nutrient media. Under appropriate conditions, a whole plant can be regenerated from a single cell, permitting the rapid production of many uniform plants. Tissue culture is now recognized as an essential tool in modern plant breeding. Since it was first developed in the early 1960s, plant tissue culture has become the basis of a major industry, providing high-value plants for nurseries. It is also an effective method for producing plants that are free from many diseases, particularly viruses.

### Molecular markers

Although genetic engineering receives much attention, of as much significance is the application of molecular markers and genetic mapping to plant breeding. Molecular markers are identifiable DNA sequences found at specific locations of the genome. Differences may exist among individuals of the same population. Different classes of markers also exist, such as restriction fragment length polymorphisms (RFLPs), amplified fragment length polymorphisms (AFLPs), and randomly amplified polymorphic DNA markers (RAPDs) or microsatellites. By determining the location and likely action of many plant genes, scientists can quickly and accurately identify those plants carrying desirable characteristics; hence conventional plant breeding can be conducted with greater precision.

Molecular markers can be used in plant breeding in several ways:

*Marker-assisted selection* is the use of markers to increase the response to selection. A quantitative trait (i.e., fruit yield, which shows continuous variation and cannot be classified into a few discrete classes) is usually controlled by many genes, called quantitative trait loci (QTL). By using molecular markers closely linked to, or even located within, one or more QTL, information at the DNA-level is used directly and selection response can be increased.

*Marker-assisted introgression*, where markers are used to increase the speed or efficiency of introgression (the introduction of new gene(s) from a population A to a population B by crossing A and B and then repeatedly backcrossing to B). Introgression may be of value, for example, in introducing genes from wild relatives into modern plant varieties.

*Studies of genetic diversity* and of taxonomic/phylogenetic relationships between plant species or between populations (or varieties) within species.

*Studies of biological processes*, such as mating systems, pollen movement or seed dispersal, and of the genetic mechanisms behind physiological traits.

### Diagnostics

The first step toward controlling a plant disease is detecting it. Identifying the disease-causing organism early makes it possible to introduce effective control measures. However, many diseases are not easily identifiable until they have reached a stage when it is already too late to prevent major damage to the crop. The development of diagnostic methods and easy-to-use kits for plant diseases has been a major breakthrough in limiting crop damage. Such kits have been developed for use both in the laboratory and in the field. Diseases that are caused by microorganisms can be diagnosed by identifying a unique feature of the organism, such as its genetic material (DNA) or a specific protein.

### Genetic engineering

Genetic engineering, also called “genetic transformation” or “genetic modification,” is the modification of genetic material (DNA) by artificial means. It relies upon the ability to isolate specific stretches of DNA using enzymes that cut DNA at precise locations. Selected DNA fragments can then be transferred into the cells of the organism. Genetically modified organisms (GMOs) are those that have been modified by the application of recombinant-DNA technology (where DNA from one organism is transferred to another organism). The term "transgenic crops" is also used for genetically modified crops, where a foreign gene (a transgene) is incorporated into the plant genome.

There are several different processes available for genetic engineering, the most common of which is to use the soil bacterium *Agrobacterium* as a go-between. *Agrobacterium* has a natural ability to alter the genetic material of plant cells so that outgrowths (or galls) are formed on the plant. This mechanism has been adapted so that instead of the genes for producing galls, desirable genetic information can be transferred into plants. The *Agrobacterium* method has been used successfully with a wide variety of plants, with the exception of the most important cereal crops.

Ballistic or biolistic impregnation is the method used for cereals and some other crops. It involves attaching the DNA to be introduced into the plant onto minute gold or tungsten particles, then firing these (like bullets) into the plant tissue. A proportion of the plant cells treated in this way take up the DNA from the metal pellets, and whole transgenic plants can then be re-grown from these cells by tissue culture.

## Biotechnology for Africa

The countries of sub-Saharan Africa still depend largely on agriculture for their economic prosperity and the welfare of the people. According to Ndiritu and Wafula (1998), current agricultural production efforts and strategies are unable to cope with the demands for food made by the rising population in the region. They state that research and development incorporating innovative technologies, such as biotechnology, are urgently needed if the decline in agricultural production is to be reversed. Today over 180 million people in sub-Saharan Africa live below the poverty line, and the number is expected to exceed 300 million by 2020. Food insecurity in sub-Saharan Africa undermines health and nutrition alike, resulting in poor maternal health, high malnutrition in children and low productivity.

While world food production has continued to increase over recent years, per capita production in sub-Saharan Africa declined by 20% from 1961-1986, and this trend appears to be continuing. There are two principal ways of increasing agricultural output: to expand the land under cultivation or to intensify production on land already under cultivation. The first is not desirable in terms of conserving land and natural resources; arable land is now in short supply in most regions. Therefore increasing yield per unit of area is the only practical solution. Ndiritu and Wafula assert that this can only be achieved through ”science-based” rather than “traditional” agriculture, and that biotechnology -- when applied appropriately -- offers this possibility without some of the adverse effects often associated with intensified agriculture.

Ives and Wambugu (1999) agree with this conclusion. Because the Green Revolution that helped Asia and Latin America to achieve self-sufficiency in food production largely passed Africa by, they maintain that the continent cannot afford to miss out on another global technological revolution such as agricultural biotechnology. Africa’s crop production per unit area of land is currently the lowest in the world, forcing the continent to import 25% of its grain needs. For instance, Africa’s production of sweet potato is 6 tons/ha compared to the global average of 12 tons/ha; similarly, Africa's average yield of maize is 1.7 tons/ha compared to a global average of 4 tons/ha.

Crops produced using the tools of modern biotechnology are now commercially available in a number of countries around the world. Some could be adapted for use in Africa (e.g., insect-resistant maize offering farmers the potential to increase yields significantly). In other cases, traits that were developed to address production constraints would need to be adapted to the different conditions in Africa (e.g., genes for insect resistance would need to be inserted into improved locally adapted African maize germplasm, or virus resistance adapted to include locally present strains). In addition to the adaptation of important input traits, Africa could benefit greatly from output traits (e.g., nutritionally improved staples such as rice and sweet potato).

Certainly within the commercial agricultural biotechnology sector the value-added or output traits are now receiving more research attention – traits such as vegetable oils with less saturated fat and enriched with beta-carotene (a precursor of vitamin A.). The commercial agricultural biotech industry appears now to be in the process of moving away from input traits such as virus and insect resistance in the direction of these types of output traits.

## Priority crops and constraints

In a recent study commissioned by the Rockefeller Foundation (*Biotechnology for African Crops,* 1999), the authors note that crop production in African countries is usually constrained by incidence of pest and disease, poor soil conditions, and abiotic stress factors such as drought and heat. These constraints are grouped into the following major categories:

- Propagation – lack of clean planting material
- General - technology development or germplasm conservation
- Disease - viral, fungal, bacterial
- Insect pests
- Weeds
- Abiotic stress - drought, heat, nitrogen deficiency
- Quality - yield or nutritional content

Many of these constraints are extremely serious. Studies of African rainfall have shown a progressive drying trend, and although the causes of frequent droughts across Africa are largely unknown, the fact that agricultural growth is severely constrained by extensive and severe rainfall shortages cannot be overlooked. Moreover, the problem of drought in many parts of Africa is often compounded by low soil fertility, particularly in semi-arid zones where soils tend to be sandy and prone to erosion and degradation. Such soils lack important nutrients like sulfur and phosphorus and have low organic matter content. Agricultural production in most parts of Africa thus requires capital-intensive chemical fertilizer inputs. Unfortunately, most farmers cannot afford these inputs; to economize, they may apply sub-optimal amounts, which can lead to further problems.

The devastating effect of pests and diseases in African agriculture is reflected in the amount of resources spent by farmers on their control. In 1995, Kenyan farmers spent approximately US $4.5 million on insecticides, US $10.5 million on fungicides, US $0.3 million on plant hormones and US $33 million to control livestock pests and diseases (Ndiritu, 1999). Many studies have shown the enormous crop and livestock losses that are a result of pre- and post-harvest pest and disease. The issue of pest and disease resistance is therefore of crucial importance to Africa.

Any debate on biotechnology for Africa must therefore be considered in the context of the continent's need for more food and the survival of its people. Biotechnology-derived solutions for the biotic and abiotic stresses mentioned above, if built into the genotypes of plants and animals, could reduce the need for, and the high costs of agrochemicals and water as well as the negative effects of diseases and weeds, thus promoting sustainable agricultural production.

The Rockefeller survey reported that applications of agricultural biotechnology were already being used to address some of the major crop constraints in Africa. The survey focused on six target crops: maize, sorghum, cassava, yams, bananas, and cowpea, all of which are staple crops. The study did not focus on research crops or targets of interest specifically to ASARECA, nor did it examine crops or technologies in advanced laboratories that may be suitable for adaptation for countries within the ASARECA network.

Interestingly, when the foundation asked 50 national research institutes from nine different African countries (only three of which were in the ASARECA network) to identify their own six target crops; 45 different crops were named. The list included both staple and export crops such as fruits and vegetables, coffee and other cash crops (cocoa, tea and cotton), root crops (potato and sweet potato), cereals (teff, millet, and barley), and legumes (groundnut and soybean). The present inventory, by contrast, specifically addresses interests of ASARECA members, using its priorities linked to ongoing research and/or available products in other parts of the world.

The ASARECA commodity research priorities as set in 1995 are given in the table below.

**Table 1. ASARECA Research Priorities. Source: ASARECA, 1995.**

| | |
|---|---|
| **1** | **Maize** |
| **2** | **Beans** |
| **3** | **Sorghum** |
| **4** | **Banana** |
| **5** | **Soil and water** |
| **6** | **Soil Fertility** |
| **7** | **Dairy** |
| **8** | **Wheat** |
| **9** | **Beef** |
| **10** | **Potatoes** |
| **11** | **Coffee** |
| **12** | **Sheep and goats** |
| **13** | **Cotton** |
| **14** | **Rice** |
| **15** | **Forestry** |
| **16** | **Cassava** |
| **17** | **Socio-economics** |
| **18** | **Groundnuts** |
| **19** | **Citrus** |

Note that in this list, maize, sorghum and banana are the only commodities that overlap with the priority list produced by the Rockefeller Foundation.

The Rockefeller study found that a limited number of viruses, diseases and pests figure prominently in the research activities identified. Biotechnology and in particular tissue culture techniques are already providing opportunities in the propagation of disease-free planting material in Africa. A wide range of biotechnology tools is already available for application in crop improvement programs, especially those related to tissue culture, micropropagation, and molecular markers.

Currently, genetic engineering is much less widely applied and is primarily in the experimental stages with many African crops. In many cases, national capacities and resources are severely limited and try to encompass too wide a range of crops. One recommendation of the Rockefeller study was therefore to focus any future support in the area of agricultural biotechnology on *"a limited number of priority crops, clear objectives, and institutes with the capacity to undertake advanced research.*"

In this report we will focus on the ASARECA priority crops, mentioning others where they are of particular importance or where there has been particularly rapid progress in biotechnology research. We will not address issues of livestock except to mention briefly animal health issues as they relate to the production of transgenic vaccines.

Many of the ASARECA networks are already involved in aspects of biotechnology, ranging from the production of tissue culture planting materials and the use of molecular markers and DNA-based diagnostic tools to more advanced transformation research in collaboration with the CGIAR centers and other ARIs. These various activities are reported in the document *Assessing the Feasibility of a Regional Initiative on Biotechnology for Agricultural Research in Eastern and Central Africa* (ISNAR/UNDP/USAID), and will not be described here in any detail.

# Biotechnology Inventory of ASARECA Priority Crops

## Maize *(Zea mays L.)*

### Background

The ASARECA network responsible for both maize and wheat is **ECAMAW** (Eastern and Central Africa Maize and Wheat Research Network). Worldwide, maize is grown at latitudes varying from the equator to slightly above 50 degrees north and south, from sea level to over 3,000 meters elevation, in cool and hot climates, and with growing cycles ranging from 3 to 13 months. It is grown in more countries than any other cereal and it is the third most important cereal crop in the world, after wheat and rice. Developing countries account for 64% of the world's maize area and 43% of global maize production.

Maize is the principal food staple in the ASARECA region, dominating the diets of the rural and urban poor. Per capita maize consumption ranges from 28 kg/year in Uganda to over 120 kg/year in Tanzania. It often provides well over 50% of staple calories. It is the most important food crop grown and consumed in Tanzania and Kenya. Maize is grown on more than 7.0 million ha annually in the region. Yields are low, fluctuating around 1.5 t/ha. Ethiopia is the top producer of maize in the region, but yields per hectare are highest in Kenya.

Maize is grown almost exclusively under rainfed conditions from sea level to 2,400 meters, and although production technology varies greatly, it is largely traditional, resulting in low productivity in most zones except the transitional highlands. There is little evidence of sustained growth in yields. The area planted to improved varieties as a percentage of total maize area in 1996 varied from 2% in Tanzania to 56% in Kenya. Only 1% of the total maize area in Tanzania was planted to hybrids, and up to 52% in Kenya. Improved varieties were grown on 8% of maize area in Ethiopia and 70% in Uganda.

Largely because of high intra-regional transport costs and a strong preference for white-grained maize, this crop dominates smallholder-farming systems within the region. Some improved varieties are available for most production zones, but the gap between their genetic potential and the yields obtained can be as much as 8 t/ha. Because of the large area planted to maize and the number of farmers involved in maize production, the development and adoption of improved technology has significant potential to elevate income and help the region become sufficient in basic grains. It is estimated that 40% of all maize produced in the region is sold by the farmer. Given the importance of maize as a food and cash crop, maize has been identified as the number one priority for ASARECA research.

Two of the CGIAR research centers have responsibility for maize -- the International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maiz y Trigo, or CIMMYT) in Mexico and the International Institute of Tropical Agriculture (IITA) in Nigeria. Their research priorities are:

- developing drought-resistant maize varieties (In 1991-92, drought destroyed two-thirds of southern Africa's maize harvest.);
- improving and disseminating maize varieties which they have developed with resistance to maize streak virus and downy mildew, major diseases of the crop in sub-Saharan Africa and Asia, respectively;
- finding ways to control *Striga,* a parasitic plant causing US $7 billion of losses to global agriculture and a major crop pest in sub-Saharan Africa.

CIMMYT considers drought, low soil fertility, insect pests, *Striga* and maize streak virus to be the major constraints to maize production in Africa, although their relative importance varies between regions and agroecologies. Drought has its most severe effect on maize production in Eastern and Southern Africa, and in addition the adverse effects of *Striga* are exacerbated by drought. Insect pests such as stem borers are a greater threat to production in humid regions.

**ECAMAW** considers the following problems to be research priorities for maize:

- low yield potential
- foliar diseases
- drought
- stalk borers
- maize streak virus
- poor soil fertility (low nitrogen)
- storage pests
- weeds (particularly *Striga*)
- termites

### *Current biotechnology products and projects*

- **Insect-resistant maize (*CIMMYT and the Kenya Agricultural Research Institute, Kenya*).** A project is underway to develop enhanced insect-resistant maize varieties by combining host plant and biotechnology-produced mechanisms. They expect to have materials with Bt-resistance to stem borer ready for field testing in the next few years.
- ***Striga* resistance (*CIMMYT and the Kenya Agricultural Research Institute, Kenya*)**. This project focuses on developing effective strategies to reduce *Striga* infestations on maize. A number of approaches are being pursued, one of which involves low-dose herbicide seed treatments of herbicide-resistant maize. So far, this has been non-transgenic, but researchers are looking at the possibilities of developing herbicide-resistant varieties via genetic engineering. Materials could be tested in the field within the next couple of years.
- **Insect-resistant maize (*Agricultural Genetic Engineering Research Institute, Egypt and Pioneer Hi-Bred International Inc, USA).*** Corn borers (*Sesamia cretica, Ostrinia nubilalis, Chilo agamemnon)* are serious insect pests in much of the corn-growing area of Egypt and are responsible for significant loss of yield. This project introduces Bt gene(s), which are known to code for proteins that are lethal to lepidopteran species into Egyptian commercial maize varieties.
- **Apomixis (*CIMMYT, ORSTOM Montpellier, France*)**. Research is underway to develop plants with apomixes – asexual reproduction through seed. This results in plants identical to the parent, which would mean that would mean that farmers

could replant seed from their own harvests of high-yielding varieties and hybrids each year instead of having to purchase new seed.

- **Resistance to maize cob rot (*Centre for Scientific and Industrial Research – Foodtek, South Africa*).** This involves maize genetically transformed for resistance to maize cob rot (*Stenocarpella maydis*), a serious fungal pathogen. Transgenic lines are being evaluated for field resistance at the ARC-GrainCrops Institute. This was the first field test in South Africa of transgenic maize transformed by a local laboratory.
- **Transformation of local maize varieties (*Department of Microbiology, University of Cape Town, South Africa*).** Development of techniques for reliable regeneration and transformation of local maize varieties from embryogenic callus.
- **Herbicide resistance (*Department of Microbiology, University of Cape Town, South Africa*).** Development of transgenic maize transformed with bar gene for bialaphos (herbicide) resistance.
- **Resistance to maize streak virus (*Department of Microbiology, University of Cape Town, South Africa*).** Development of transgenic maize with resistance to maize streak virus (in progress).
- **Rust resistance (*Dr. Scot Hulbert, Kansas State University, USA*).** The gene for rust resistance caused by *Puccinia sorghi* has been cloned from maize and engineered back into maize. It also gives some resistance to southern rust (*P. polysora*). Greenhouse trials are underway and field trials planned in 2001.
- **IMI-CORN®** (***American Cyanamid***). Introduced in 1992, imidazolinone-tolerant and -resistant corn allows growers to apply the flexible and environmentally friendly imidazolinone herbicides to corn. Registration of LIGHTNING™ herbicide, a new imidazolinone specifically for use on IMI-CORN®, was approved by the EPA on March 31, 1997. One post-emergence application of LIGHTNING™ herbicide provides both contact and residual control of broadleaf and grassy weeds resulting in maximum yield potential.
- **LibertyLink® Corn** (***AgrEvo).*** Introduced in 1997 in the United States and 1998 in Canada, LibertyLink® Corn allows growers to apply Liberty® herbicide over the top during the growing season. Liberty herbicide kills over 100 grass and broadleaf weeds with no crop injury. LibertyLink® Corn hybrids are offered by seed company partners like Pioneer, Novartis, Cargill, Garst and over 100 other seed companies. Liberty® herbicide is offered by AgrEvo.
- **DeKalBtTM Insect-Protected Hybrid Corn** (***DeKalb Genetics***). Approved in 1997, select DeKalb leader hybrids are now available with built-in protection against the European corn borer.
- **DeKalb Brand Roundup Ready® Corn** (***DeKalb Genetics***). Approved in 1998, DeKalb offers several elite hybrids with resistance to Roundup UltraTM herbicide.
- **DeKalb GR hybrid corn** (***DeKalb Genetics***). Approved in 1996, DeKalb GR hybrids provide growers the added weed control benefits of over-the-top glufosinate herbicide application during the growing season.
- **High pH-tolerant corn hybrids** (***Garst Seed Company***). These corn hybrids are capable of growing successfully on the severely alkaline soils that characterize the western U.S. corn belt.
- **Gray leaf spot–resistant corn hybrids** (***Garst Seed Company***). Corn hybrids tolerant to the disease *Cercospora spp.,* which attacks corn hybrids in the central and southeastern U.S. corn belts.

- **G-StacTM corn hybrids** (***Garst Seed Company***). Corn hybrids featuring "stacked" genes providing multitask capability. For example, hybrids that contain genes for the control of European corn borer (Bt), genes for resistance to Liberty® herbicide and genes for resistance to imidazolinone herbicide all in the same corn hybrid.
- **Roundup Ready® corn (*Monsanto*)**. Approved in 1997, Roundup® Ready Corn allows over-the-top applications of Roundup® herbicide during the growing season for superior weed control.
- **YieldGard™ insect-protected corn (*Monsanto*)**. The YieldGard™ gene provides control of the European corn borer throughout the corn plant during the season.
- **NatureGard® hybrid seed corn (*Mycogen*)**. These corn plants express a Bt protein toxic to European corn borer that reduces or eliminates the need for insecticides.
- **IMI-corn (*Mycogen*).** Corn hybrid that can tolerate application of imidazolinone herbicides.
- **NK Knockout™ corn, NK YieldGard™ hybrid corn, Attribute™ B.t. sweetcorn (*Novartis Seeds*)**. Novartis Seeds has produced several corn varieties that have been modified to provide natural protection against certain pests.
- **SeedLink corn (AgrEvo)**. These plants provide a more reliable pollination control system for corn seed production. The use of the SeedLink System eliminates the need for hand or mechanical detasseling. Availability expected within 6 years.

### Prospects

Maize has been one of the most intensely studied crops at the genomic level, largely because of the heavy involvement of private sector companies and the enormous market potential of maize in the developed world. Some molecular techniques are now routine in maize breeding, while others will soon be available in the public sector. Maize stands out as the crop that is most often subject to advanced biotechnology applications such as genetic markers and genetic engineering. There are clearly numerous efforts underway in maize biotechnology that are of direct interest to ASARECA; i.e., soil fertility, virus resistance, weeds, and borers. Adaptive research to develop African maize varieties with biotic and abiotic improvements could be conducted if ASARECA (and other African research institutions) expanded their partnerships with the private sector companies and advanced research institutions that currently hold much of the transgenic technology for maize.

## Bean (*Phaseolus vulgaris*)

### Background

The ASARECA Network responsible for bean is **ECABREN** (Eastern and Central Africa Bean Research Network). Bean is a major staple food. In fact, *Phaseolus* bean, or common bean, is the world's most important food legume. Farmers grow common beans in two forms, as dry beans and snap beans (the green pods are consumed as a vegetable). Dry beans account for 57% of the world's food legume production, having twice the production and market value of chickpeas, the next leading food pulse. Another 3 million metric tons of snap beans are also produced annually.

Latin America produces nearly half of the world's supply of dry beans. Brazil, Mexico, and Central America are the major producers. Nearly 80% of dry bean production in developing countries occurs on small-scale farms. Estimated global production of dry beans is approximately 18 million metric tons annually, with a market value of US $10.7 billion.

Beans are nutritionally rich, especially in protein and iron, and are a good source of dietary fiber and complex carbohydrates. Given their nutritional quality and high consumption levels, beans make an important contribution to human nutrition, especially for poor consumers. In addition to high quality protein, a single serving (1 cup) of beans provides at least half the USDA-recommended daily allowance of folic acid and 25-30% of the daily-recommended iron levels, 25% of the daily requirements of magnesium and copper, and 15% of potassium and zinc.

Africa, where women on small farms are the primary bean growers,is considered to be a secondary center for bean genetic diversity. In Africa bean production is divided between two major agroecological zones: highlands above 1,500 masl (meters above sea level), and mid-elevation (1,000-1,500 masl). A further 3% of the bean area is in the lowland zone. Both principal production areas have high population densities. Farmers plant about 3 million hectares of beans annually in Eastern, Central and Southern Africa, usually a mixture of varieties.

Beans are the second most important source of human dietary protein in the ASARECA region, and the third most important source of calories. Bean provides 60% of dietary protein in Rwanda and in much of the region is the principal source of dietary protein for the urban poor. In the widespread maize-based cropping systems of mid-altitude areas of Eastern and Southern Africa, beans contribute up to 30% of dietary energy. Bean consumption in the ASARECA region exceeds 50kg per person per year in some places and as high as 66kg in rural districts of Kenya.

Over 3 million hectares of beans are grown annually in the ASARECA region. The principal producing countries are Burundi, Congo, Ethiopia, Kenya, Rwanda, Tanzania, Uganda and Madagascar. Bean is important for small farmers for cash generation, both for total farm income as well as for providing a marketable product at critical times when farmers have nothing else to sell. Recent surveys in Uganda show that many households sell beans after harvest to meet household needs, and later repurchase beans for food. Increased production accompanied by improved storage would raise both income and food security.

The importance of bean as a market crop ranges from the less than 20% of the harvest that is marketed in some densely populated areas to the more than 90% of the harvest marketed by small-scale producers in the Rift Valley of Ethiopia. Although the major bean market flows are within countries, there is also considerable cross-border trade to satisfy urban demands. Kenya, Malawi, Rwanda and Sudan are net importers, whereas Tanzania and Uganda are major exporters to these regional markets.

Beans are attractive crops for farmers, because of their adaptability to different cropping systems and short growing cycle. Beans are well adapted to intensification of land use through doubling cropping. They are quick growing and shade tolerant and are often used in intercropping systems. Two or three crops can be grown annually in many areas. Another opportunity for intensification is through increased cultivation of climbing beans in the East African highlands. Current efforts to breed climbing bean lines with tolerance to warm temperatures may broaden their range of adaptation.

Currently, average bean yields in Africa are low, with low levels of external inputs. Experimental yields commonly exceed farmer production by more than 100% (i.e., by one tonne per hectare). The disadvantage of the bean plant is its susceptibility to many diseases and climatic stresses. Some diseases affecting bean production are angular leaf spot, rust, common bacterial blight, bean stem maggot, bean common mosaic virus and bean golden mosaic virus. Moreover, about 60% of bean production in developing countries suffers from low soil phosphorus availability.

In the past decade, bean research in Africa has emphasized variety development and soil improvement for overcoming production constraints for small-scale farmers in highland production areas. Although yields in Africa have increased modestly during recent years, the rate of increase in bean production still lags behind population growth. Full realization of the crop's potential to combat hunger and poverty in this region requires a major research effort to overcome the constraints of low soil fertility, drought, and major diseases and insect pests.

The major biotic and abiotic constraints to bean production in the region are:

- *Diseases*
  - Angular leaf spot
  - Anthracnose
  - Root rots
  - Common bacterial blight
- *Insect pests*
  - Bean stem maggot
  - Bruchid
- Nitrogen and phosphorus deficiency
- Drought

Low soil N and P availability can potentially be managed with inorganic and organic fertilizer use, accompanied by varieties efficient in nutrient use. While local varieties tend to be susceptible to many of the biotic constraints, increasing availability of multiple resistant or tolerant varieties to the biotic stresses is expected to increase the use of inputs in favorable environments and lead to substantial rises in productivity.

A contrasting situation is presented by snapbean production, where input use (pesticides) is currently excessive and threatens exports. These producers urgently need genetic resistance to rust and pest management techniques for stem maggot and thrips. Developing new varieties resistant to major diseases –namely, rusts and common blight -- will be necessary to reduce chemical use and increase sales. In recent years root rot diseases initially observed in the Great Lakes region have spread to high-potential areas of bean production in Central and Eastern Africa, particularly Western Kenya and southwestern Uganda.

CGIAR's Centro Internacional de Agricultura Tropical (CIAT) holds the global mandate for bean research. In partnership with national agricultural research systems and regional networks, CIAT works on increasing bean productivity in several regions through cultivar development and management practices. In addition, CIAT maintains the largest global collection of bean germplasm and related species.

**ECABREN** is currently collaborating with ARIs on projects using molecular markers to characterize bean germplasm, and also diagnosis and characterization of bean pathogens.

### *Biotechnology products and projects*

- **Drought resistance (*Centre for Tropical Agriculture, CIAT, Colombia*).** Transfer of drought tolerance from tepary to Phaseolus bean (genetic exchange between different species) assisted by molecular markers is part of the bean improvement program.
- **Resistance to bean golden mosaic geminivirus (*Dr. Doug Maxwell, University of Wisconsin, USA and Dr. Josias de Faria, EMBRAPA, Brazil*).** Transgenic Phaseolus beans have been developed to express viral antisense RNAs and show delayed and attenuated symptoms to bean golden mosaic geminivirus. This virus causes serious losses particularly in Latin America and is transmitted by whitefly vectors.

### Prospects

Beans have proved to be notoriously difficult to transform, and little progress has been made in applying biotechnology to *Phaseolus* bean. The first report of successful transformation of bean was in 1993, but since then remarkably little seems to have been achieved with this crop. Some transformation work has been carried out for virus resistance, but not necessarily on viruses of importance in Africa.

Therefore, although bean is an important priority crop for Africa, bean biotechnology is still in the early stages and is unlikely to produce results within a 5-year timeframe. The most promising target for transformation would be the use of previously isolated Bt genes against insect pests. However, reliable transformation and regeneration systems for bean need to be further developed before such techniques can be effectively applied. Research into drought resistance is still in the very early stages, and although an important goal, is also unlikely to be achieved in the near term.

## Sorghum

### Background

The ASARECA network responsible for sorghum and millet is **ECARSAM** (the Eastern and Central Africa Regional Sorghum and Millet Network). Sorghum is the fifth major cereal crop in the world after wheat, rice, maize and barley. It is also grown in the United States, Australia, and other developed nations for animal feed. Sorghum is an annual grass that is particularly adapted to drought prone areas; a crop suited to hot, semi-arid tropical environments with 400-600 mm rainfall--areas that are too dry for maize. Sorghum is also found in temperate regions and at altitudes of up to 2,300 meters in the tropics. In 1996, the global area harvested to sorghum was about 47 million hectares (24 million of which were in Africa). Total sorghum production for the same period was 69 million metric tons. Sorghum originated in northeast Africa where a large variability in wild and cultivated species is still found today.

Sorghum and millet form basic staple food in the Eastern and Central African region and are mainly cultivated by small farmers. Sorghum and millet are consumed in many forms, of which the most common are leavened bread, porridge, and both non-alcoholic and alcoholic beverages. ASARECA has ranked sorghum third in a list of regional agricultural research priorities after maize and beans. In Eastern and Central Africa, sorghum is grown on approximately 10 million ha and millet on over 3 million ha. Yields are generally very low and the bulk of production is used for food, forming the staple cereal in Sudan, and is an important component of the diet in Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Tanzania and Uganda. Small quantities are used for animal feed and industrial production. Approximately 60% is consumed at farm level and 40% is sold in local markets. Only Sudan exports sorghum (<5% production), whereas Ethiopia, Somalia and Kenya are importers. The whole region is a net importer of sorghum to the extent of 350,000 tons annually.

Both national and international programs have been involved in breeding work to produce improved sorghum and millet cultivars, crop production research to identify improved agronomic and crop protection practices, and research on processing and utilization of grain. Substantial numbers of improved cultivars have been developed; however, there has so far been little progress in introducing them to farmers.

**ECARSAM** encourages the adoption of new technologies (improved cultivars, crop protection and fertilizer use) and the use of grain in small-scale processing. The network also aims to support ongoing research work to develop new technology, particularly in the integrated management of *Striga*, pests and diseases. **ECARSAM** research priorities include:

- management of *Striga*
- variety development
- pest resistance -- stem borer, shoot fly, midge
- disease resistance -- charcoal rot, kernel smut, rusts, ergot
- acid soil tolerance

Next to marginal agricultural land and drought, insect pests are a primary constraint in sorghum production and are associated with the crop from planting through storage. The majority are insect species of worldwide economic importance. Approximately 150 species are reported to infest sorghum, but the most serious are shootfly (*Atherigona soccata*), stem borers (*Chilo partellus*, *Busseola fusca*, *Diatrea ssaccharalis*, *Sessamia calamistis*, and *Eldana saccharina*), and the sorghum midge (*Contarinia angustatus*), in addition to armyworms, and several caterpillars, grasshoppers and storage insects. Actual data on yield loss is sketchy, but estimates suggest that losses in sorghum caused by the major species of insects are over 20% in Africa and 32% in Asia. In Africa and Asia alone these losses are estimated to result in an annual loss of 8.9 million tons of food grain (ICRISAT, 1992). The use of chemical insecticides is impractical in most African farming systems, and management through host plant resistance is considered the only viable long-term control strategy. Apart from sorghum midge, which has been successfully combated in India, Australia, and the USA, and two varieties that have tolerance to stem borer, sorghum pests have not yielded to conventional breeding approaches. It has proved difficult to breed good yields and resistance into the same cultivars. Resistance traits are quantitatively inherited and have proved difficult to manipulate.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India serves as a world center for improving grain yield and quality of sorghum. ICRISAT holds 36,729 accessions of sorghum.

Sorghum has received relatively little attention in terms of molecular technologies, but the first genetic maps of sorghum were published in the early 1990s, and the first successful transformation of sorghum was achieved and published in 1993. These two major advances should have allowed improvement of sorghum through greatly enhanced traditional breeding and genetic engineering. However, despite continued genetic mapping work, no transgenic products are near field-testing at this time (Richard Frederickson, personal communication).

According to Bennetzen (1995) the chief limitations to improving sorghum are not technical, but are due to the lack of detailed genetic mapping of important sorghum traits and a general lack of resources allocated to the study. Although many useful DNA markers have been identified and mapped, there are still too few fingerprinted lines, mapped traits and mapped populations. Moreover, populations that have been mapped have often been too small to provide precise information. Important single genes and quantitative traits need to be placed on the sorghum genetic map, and require screening under a variety of environmental circumstances and from a number of parental sources. Such comprehensive studies will be needed to identify regions of the sorghum genome that enhance productivity and to identify lines with superior alleles within these regions.

This important gene identification and mapping process can be greatly assisted by the use of information and markers from other grass species. Research has shown that the grasses have very similar gene content and regions of conserved gene order. Theoretically it should be possible to transfer the cold tolerance of barley or the seedling vigor of maize to sorghum once these traits have been identified and cloned.

### *Biotechnology products and projects*

- **Genetic map of sorghum (*Texas A&M University, USA*)**. The Sorghum Biotechnology Program at Texas A&M aims to i) develop a high-resolution molecular map of sorghum; ii) facilitate the application of molecular markers to sorghum improvement; iii) develop new methods for gene identification, gene cloning and germplasm screening for important traits; iv) improve and apply gene transformation to sorghum; and v) develop and manage a sorghum genome database and DNA clone repository. Important genes mapped so far include: resistance to head smut, downy mildew, anthracnose and head blight.
- **Stem borer resistance (*ICRISAT, India*).** ICRISAT is currently carrying out research to introduce Bt genes into sorghum for stem borer resistance.
- **Transformation of sorghum (*CSIR, Bio/Chemtek, South Africa*).** CSIR began tissue culture of African sorghum lines (*Sorghum bicolor* L. Moench) for regenerability potential, screening various media combinations and genotypes in

1996. Two years later, CSIR reported on a single chimeric transgenic sorghum plant. CSIR is currently in the process of optimizing sorghum transformation systems to obtain stably transformed African grain sorghum. CSIR is also beginning a project on the genetic enhancement of nutritional quality of grain sorghum with a focus on a transformable Ethiopian line and three Ghanaian lines.

- **Molecular markers of sorghum (*CSIR, South Africa*).** CSIR is also involved in the molecular markers and diagnostics of sorghum. The molecular marker work includes the development of markers linked to agronomic traits of interest and are mainly used in marker-assisted selection (MAS).
- **High lysine sorghum (*Pioneer Hi-Bred, USA*).** Pioneer has successfully transformed sorghum with a high lysine gene to evaluate the transformation system, but currently has no plans to commercialize this trait. Any future commercial products will be in a hybrid sorghum variety.
- **Quality traits in sorghum (*Aventis, USA*).** Aventis has an interest in introducing quality traits into sorghum using constructs from maize. However, there are currently no plans for developing a commercial product.

## Prospects

Since *Striga* is a major pest of sorghum, it is worth considering whether control strategies involving herbicide resistance genes would be effective. Herbicide resistances could be engineered into sorghum relatively easily, but it is unclear whether this would be of use in sorghum cropping systems in Africa where most farmers may not have access to herbicides, or the money to buy them. Field screening for *Striga*-resistant cultivars is often unreliable and slow because of the inconsistent nature of *Striga* infestations both within the same field and among different fields across years. Some resistant cultivars have been identified where resistance is recessive and controlled by one or two genes, and in some varieties this may be linked to the low production of stimulants that cause the *Striga* seed to germinate. This stimulant production might be a useful target for genetic engineering.

Insect resistance strategies involving Bt genes might be a useful approach in areas where stem borer and other insect pests are particularly damaging. The Bt genes would first need to be inserted into locally adapted sorghum germplasm. ICRISAT is currently working with a number of other institutions to introduce Bt genes into sorghum varieties.

In terms of output traits, engineering higher levels of expression of amylase genes in the endosperm could be accomplished with little difficulty and could improve sorghum’s malting properties. Other conventional breeding aims include improving the nutritional balance of sorghum seed proteins, altering the levels and types of starches and oils, and improving the forage quality of the leaf and stalk. Most of these goals could also be addressed by using experience gained from other crops.

The lack of significant impact on sorghum drought resistance by traditional breeding has also raised high expectations from biotechnology. However, the greatest difficulty in applying biotechnology to improve stress resistance in plants is the inadequate understanding of plant responses to drought.

# Millet

## Background

The ASARECA network responsible for sorghum and millet is **ECARSAM** (the Eastern and Central Africa Regional Sorghum and Millet Network). See previous section on sorghum for further information.

Millet is a collective term for the grain of a large number of small-seeded grasses that are grown as cereal crops. Millets grow well in arid and semi-arid environments, requiring less water than any other grain. While developing countries in Asia still produce the majority of the world's millets, Africa is becoming a major area of production, which has risen 25% there since the early 1970s. Its place in domestic diets there is growing steadily. All other regions of the world, however, have registered declines in total output, and even in Africa per capita production has dropped notably. The CGIAR focuses on two types of millet: finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*).

Pearl millet is a robust annual, growing up to 4 meters in height. It is usually grown as a dryland dual-purpose grain and fodder crop in semi-arid regions of Africa and India. It is also grown in the Americas as a hot season forage crop throughout the tropical and subtropical lowlands, and as a mulch component in no-till soybean production in Latin America. Finger millet is a smaller grass, adapted to more humid conditions, and is grown for its straw as well as its grain. Because it is often grown in more favorable production environments than pearl millet, its grain yields can be competitive with those of rice and other improved cereals. Both pearl millet and finger millet are natives of Africa.

Pearl millet is very hardy. It produces grain and fodder under very hot and dry conditions, and on soils too poor for sorghum and maize. Its combination of rapid growth rate when conditions are favorable, high temperature tolerance, and ability to extract mineral nutrition and water from even the poorest soils make it unbeatable in the world's harshest agricultural environments. Pearl millet can withstand drought, heat, insects, poor soils, and flash floods. However, it is very susceptible to downy mildew. This disease can be devastating, particularly in India where plant breeders have introduced genetically uniform single-cross hybrids that make the crop especially vulnerable to epidemics.

Finger millet has outstanding properties as a subsistence food crop. Its small seeds can be stored safely for many years without insect damage, which makes it a traditional component of farmers' risk-avoidance strategies in drought-prone regions of Eastern Africa and South Asia. Further, its grain tastes very good and is an excellent dietary source of calcium, iron, manganese, and methionine -- an amino acid lacking in the diets of hundred of millions of poor people who live on starchy foods such as cassava, plantain, polished rice, and maize meal. Finally, it is productive in a wide range of environments and growing conditions. However, finger millet is extremely susceptible to *Pyricularia* blight, a close relative of rice blast.

During 1992-94, the average global area from which millet grain was harvested was about 38 million hectares (19 million hectares in Africa and 17 million in Asia, with much smaller areas in the Americas, Oceania, and the former USSR). Yields averaged about 750kg per hectare. Annual global production for this period was about 28 million tons, of which about 22 million tons was used each year for direct human consumption. Production statistics for the various millets are often lumped together (sometimes with sorghum) so it is difficult to obtain reliable estimates of the areas sown to individual species, but the most recent estimate suggests that about 50% of global millet grain production is pearl millet, with about 10% for finger millet.

Millet grain is the basic diet for farm households in the world's poorest countries and among the poorest people. In the Sahelian zone of Africa, pearl millet is the staple cereal. Millet straw is a valuable livestock feed, building material, and fuel in those farming systems. Exports and imports of millet grain are negligible, suggesting low demand and/or unreliable availability of marketable surpluses for this commodity in world markets.

The International Center for Agricultural Research in the Semi-Arid Tropics (ICRISAT) has the CGIAR global research mandate for pearl millet. Research priorities are downy mildew (the most important disease of pearl millet worldwide), the parasitic witchweed (*Striga*) and several insect pests, along with improved tolerance to drought and low soil fertility. Very little progress has been made with biotechnology applications for millet. No transgenic products are yet near field-testing, but some molecular work is being carried out. Current projects are listed below.

### *Current biotechnology products and projects*

- **Molecular map of pearl millet (*ICRISAT*).** ICRISAT working with UK and Indian collaborators have developed a molecular map of pearl millet and applied molecular techniques to distinguish different races of the pathogen-causing downy mildew.
- **Identification of race-specific quantitative trait loci (QTLs) (*ICRISAT*)**. Multiple genes are required for resistance that is effective against the different pathogen races of downy mildew. ICRISAT and its collaborators have identified race-specific quantitative trait loci (QTLs) conferring resistance against several such pathotypes. The first pearl millet marker-assisted backcrossing program, transferring these resistances into agronomically elite hybrid parental lines, is nearing completion. This work should lead to more durable resistance to downy mildew.
- **Transformation protocols for pearl millet (*Centre for Scientific and Industrial Research, Foodtek, South Africa*).** Development of transformation protocols for pearl millet to develop resistance to downy mildew. This work is still in the early stages.

### Prospects

As with sorghum, the technology for transformation and regeneration of millet is still in its early stages, and there are unlikely to be any transgenic products available in the near term. Work in South Africa is, however, encouraging, and once reliable protocols are developed, insect resistance (using Bt genes) and herbicide resistance strategies could be readily applied to millet.

# Banana and plantain (*Musaceae*)

## Background

The ASARECA network responsible for banana is **BARNESA** (Banana Research Network for Eastern and Southern Africa). Banana and plantains, which are derived from the wild species *Musa acuminata* (AA) and *Musa balbisiana* (BB), are staple food crops for millions of people in developing countries. In terms of gross value of production, bananas and plantains are the developing world's fourth most important crop after rice, wheat and maize. They reach their greatest importance as a staple food crop in parts of Eastern Africa, where annual consumption is over 200 kg/capita. Today, about 90% of production takes place on small farms, and this fruit is consumed locally. Only 10%, mainly from commercial plantations in Latin America and the Caribbean, enters world trade. While Latin America is the world leader in banana production for export, the African region is the world's largest non-export producer and has a strong lead in output for domestic consumption. Banana is one of the world's top five internationally traded tropical commodities, with an annual export value of about US $5.3 billion. Total world export of banana in 1995 was approximately 11.3 million tons from 32 countries.

Approximately one-third of global banana production is in sub-Saharan Africa, where it provides more than 25% of food and energy requirements for 70 million people. Eastern Africa alone produces nearly 20 million tons of bananas annually, and the East African Highland bananas, which are unique to this region, provide a staple food crop for about 20 million people. Bananas are grown predominantly by small-scale farmers, and as they produce fruit all year round, they play an important role in bridging the "hunger gap" between crop harvests. In addition to being a staple food crop for rural and urban consumers in the region, the crop is also an important source of rural income through sale in local markets, and it has great potential for development as an export commodity. On steep highland slopes, banana is important in combating soil erosion and improving long-term fertility of the soil. Moreover, its canopy provides protection for other crops such as bean, groundnuts, cucurbits and coffee.

Bananas and plantains are best known as a food crop, although almost every part of the plant can be used in one way or another. Leaves are used for thatching, for wrapping food during cooking, as bowl covers and as covers for earth ovens to hold in the heat. A high-quality fiber can be extracted from the leaves and pseudostem; it is used in textile manufacture for making ropes and strings and for the production of various handicrafts. The fruits are also sold in pulp form, chips, dried and in confectionery, and are used in some countries to produce alcohol. In mixed-farming systems, bananas provide ground shade and nursery for shade-loving crops, such as cocoa, coffee, black pepper and nutmeg. Rich in carbohydrates, bananas and plantains are of great nutritional significance, supplying minerals, notably phosphorus, calcium, and potassium. They are particularly rich in vitamin C and contain significant amounts of several other vitamins, such as vitamin A.

Rising population pressure in the East African highlands has led to an intensification of production and declining soil fertility in banana-growing areas. Pest and disease pressures have also increased, leading to a situation where a well-managed banana garden in East Africa, previously expected to last up to 50 years, is deteriorating after only 4 years. The most serious constraint to banana production in sub-Saharan Africa is black Sigatoka, a leaf spot disease caused by the fungus *Mycosphaerella* *fijiensis*. This disease, introduced into Africa in the 1970s, has spread rapidly. It causes severe leaf necrosis and can reduce yields by 30-50%. All the traditional plantain cultivars in West and Central Africa are susceptible to the disease, as are most of the widely grown cultivars in Eastern Africa. Considerable losses are also caused by Fusarium wilt, caused by the soil-borne fungus *Fusarium oxysporum* fsp *cubense*. The banana weevil (*Cosmopilities sordidus*) and a complex of nematodes (*Pratylenchus* sp. and *Helicotylenchus*) cause severe losses by interfering with nutrient uptake by the roots.

Research priorities set by **BARNESA** are:

- broadening the genetic base of *Musa* in Eastern Africa
- addressing the major pest and disease problems
    - Sigatoka
    - *Fusarium*
    - Banana Streak Virus
    - Banana Bunchy Top Virus
    - weevils & nematodes
- post-harvest technology and processing
- conservation of the natural resource base
- understanding the socio-economic factors in banana based systems

**BARNESA** has no biotechnology projects at present, but considers biotechnology to be of potential use in the production of clean planting material (molecular diagnostics, tissue culture etc.), and in producing transgenic plants with increased disease resistance. Un particular the shortage of disease-free planting material is seen as a major constraint to production.

Two CGIAR centers conduct research on bananas and plantains: The International Network for the Improvement of Banana and Plantain (INIBAP) in Montpellier, France, which is a program of the International Plant Genetic Resources Institute (IPGRI); and the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria and Kampala, Uganda.

With few exceptions, the bananas grown today differ little from those grown a thousand years ago. This is largely because improvement by conventional breeding has been extremely difficult and the resources for such efforts limited. For at least the past decade, researchers have predicted that biotechnology would have a major impact on banana improvement, but so far progress has been slow. However, this may change (Dale, 1999). There are now very active research programs in Australia, Africa, the United States and Europe working towards direct insertion of useful genes by genetic engineering or through marker-assisted conventional breeding. Micropropagation of banana has been used extensively over the past 20 years, but transformation methods for banana were not published until the mid-1990s. Now these techniques are a reality and it is possible to insert genes into banana, the next important research step is to express those genes at the desired level and time and in the desired tissue.

The “easiest” targets of research for transformation of banana are virus resistance and improved post-harvest qualities, specifically shelf life. Unfortunately, the traits in greatest demand from growers are fungal disease resistance and nematode resistance, traits for which the technology is either not yet available or still unproven. In terms of fungal resistance three basic approaches are being followed. Two involve non-specific genes not from banana, such as those encoding anti-microbial proteins

(AMPs) and systemic acquired resistance. The third involves specific resistance genes isolated from resistant banana. The availability of a high-density map of the *Musa* genome along with molecular markers would greatly assist this process.

Possibly the traits most amenable to manipulation in transgenic bananas are control of ripening and discoloration. Technology for both these characteristics is well advanced in other crops -- e.g., tomatoes-- and bananas are a good target for this approach as they are "climacteric," meaning that their ripening can be induced and controlled by ethylene. Field trials of transgenic bananas with altered ethylene metabolism are ongoing.

The concept of edible vaccines to prevent **human** diseases such as Norwalk Virus, hepatitis, and enteric diseases such as those caused by *E. coli*has proven to be a very popular one, and there is already some evidence that an immune response can be elicited in laboratory animals by feeding on plant material expressing an antigen. Bananas are considered by some to be a prime vehicle for expressing such vaccines. Whether it turns out to be practical to deliver vaccines in an edible banana fruit or not, bananas would still be an excellent candidate as a bioreactor to produce valuable proteins that could then be extracted from the fruit.

There are already at least two large-scale field trials and a number of glasshouse trials of transgenic banana with useful traits, namely virus resistance, fungal resistance and improved fruit quality.

### *Current biotechnology products and projects*

- **Modified ripening banana and black Sigatoka resistance (*Zeneca Plant Sciences, now Syngenta, Basel, Switzerland*).** Zeneca is developing bananas with resistance to black Sigatoka, and also modifying ripening characteristics in bananas. This will reduce the need for chemical fungicides, as well as improve the agronomics of production and the post-harvest quality to the consumer. Field tests are ongoing.
- **Sigatoka resistance (*Dr. Rony Swennen, KUL, Belgium*).** Bananas have been transformed with genes coding for antifungal proteins and these plants have performed well in contained trials. Approval is still awaited for field trials in Nigeria in collaboration with IITA. A recent proposal is to test these plants (in parallel or as an alternative) in Kenya, where biosafety procedures are already in place.
- **Nematode resistance (*Prof. Howard Atkinson, University of Leeds UK; Dr. D. Harris, University of Wales, UK*).** A gene coding for the production of cysteine protease inhibitor was linked to a root-specific promoter and used to transform rice cultivars to be resistant to nematodes. Optimized versions of this construct are being used to transform banana cultivars for testing in the Windward Islands (British Department for International Development funding).
- **Resistance to banana viruses – Banana Bunchy Top Virus, Banana Bract Mosaic potyvirus *(Dr. J. Dale, Queensland University of Technology, Australia*)**. A large number of lines of transformed Bluggoe and Cavendish varieties transformed with BBrMV-derived resistances designed to trigger RNA-mediated resistance are currently in screening trials.
- **Bananas containing edible vaccines (*Dr. Charles Arntzen, president, Boyce Thompson Institute for Plant Research, USA*).** Researchers are investigating

the genetic incorporation of vaccines into food plants. BTI is developing a hepatitis vaccine in bananas, selected because they are one of an infant's first foods, can be eaten raw and are widely available throughout the world. It is estimated that this system could deliver the vaccine at 2 cents a dose versus $125 for a vaccine injection.

### Prospects

Transformation of bananas with useful characters is now a real possibility, and one that could be exploited with relatively immediate benefit to Africa. Perhaps the highest priority is that of resistance to black Sigatoka. Several different public- and private-sector groups have developed approaches that are already fairly advanced. Some of the varieties already transformed are applicable to Africa, and once the techniques are routine, transferring the traits to other local varieties (such as the East African Highland types) should be fairly straightforward. Collaborations to encourage this should be pursued. This is also the case with virus resistance, which is a high priority in the region. One of the factors that has delayed progress in this area is the lack of appropriate biosafety structures in countries in the region. Consequently, it has not been possible to field-test any of the transgenic germplasm. Every effort should be made to put biosafety regulations in place.

The Cavendish banana variety, which is the common dessert banana in international trade, is obviously the most researched variety, and it has been the focus of much of the work on ripening and post-harvest characteristics. Although it is grown in Africa, it is not of major importance there, but any traits researched on the Cavendish could be transferred to locally popular varieties if postharvest quality was seen as an important priority for research. Some research on transgenic resistance to nematodes and weevils is promising, although it is still in the very early stages.

## Wheat (*Triticum* spp.)

### Background

The ASARECA network responsible for both maize and wheat is **ECAMAW** (Eastern and Central Africa Maize and Wheat Research Network). Wheat, a cereal grass of the *Gramineae* (Poaceae) family and of the genus *Triticum,* is the world's largest cereal-grass crop. It has been cultivated for at least 6,000 years and its status as a staple is second only to rice. Unlike other cereals, wheat contains a high amount of gluten, the protein that provides the elasticity necessary for high-quality bread. Over 30,000 varieties of wheat exist between the two major species: bread wheat (*Triticum aestivum*) and durum wheat (*Triticum durum*). Hard *T. aestivum* wheat is high in protein (10-17%) and yields flour rich in gluten, making it particularly suitable for yeast breads. The low-protein (6-10%), softer *T. durum* type yields flour lower in gluten, better suited for tender baked goods, such as biscuits, pastries, and cakes. *T. durum* wheat, although high in gluten, is not good for baking. Instead, it is often ground into semolina, the basis for excellent pasta, such as spaghetti and macaroni. Wheat grain, a major source of energy in human diet, is higher in protein content than almost all other cereals. On an average the kernel contains 12% water, 70% carbohydrates, 12% protein, 2% fat, 1.8% minerals, and 2.2% crude fibers. Thiamine, riboflavin, niacin, and small amounts of vitamin A are also present. A pound of wheat contains about 1,500 calories. In West Asia and North Africa, as well as Central Asia, it contributes more calories to diets than all other cereals combined.

Global production of wheat is now approaching 600 million tons, with international trade approximately 100 million tons annually. In 1992-94, Asia accounted for 67% of the developing world's production of wheat (39% of the developing world's production in China), 19% West Asia and North Africa, 7% in Latin America and the Caribbean, and less than 2% in sub-Saharan Africa. By 1992 wheat provided 20% of total developing country food supply, as compared to 15% in the early 1970s. In 1992-94, developing countries accounted for 45% of world wheat production (551 million tons) and 46% of world wheat area (219 million ha). For the developing regions as a whole, the annual demand for wheat is projected to grow at 3% over the first decade of the century. Demand for wheat is expected to rise particularly rapidly in sub-Saharan Africa, at 5.1% per year due to increasing urban demand.

Wheat is grown on about 2 million ha in Eastern and Central Africa, mostly in Ethiopia, Kenya and Sudan. Wheat yields are low, fluctuating around 1.5 t/ha. Per capita consumption ranges from around 2.5 kg/year in Uganda to over 30 kg/year in Ethiopia, where it is a traditional crop, and over 40 kg/year in the Sudan. Annual imports of wheat are high and growing in many ASARECA countries, regionally often surpassing 1 million tons each year, representing a cost of over US $185 million to the region in foreign exchange. Most of these countries produce barely 50% of their domestic demand. Wheat imports dominate food aid: Between 1992-1995 wheat accounted for approximately 80% of the total volume of cereal aid supplied to Ethiopia. Wheat is identified as the eighth priority for regional research by ASARECA.

Two CGIAR centers, CIMMYT and ICARDA, have contributed to developing and distributing improved varieties of wheat in collaboration with national research institutions. CIMMYT serves as the world center for the improvement of bread wheat, durum wheat, and triticale and is also a repository for a significant proportion of the world's publicly available genetic resources of bread wheat. CIMMYT's semi-dwarf wheats have been bred to yield well under a range of cropping conditions, both favorable and unfavorable, and yield at least as well as locally adapted wheats when climatic conditions are unfavorable, yet yield much more when conditions improve. A collaborative program between CIMMYT and ICARDA is responsible for the improvement of wheat in West Asia and North Africa.

The following list of priority researchable constraints for wheat was developed by **ECAMAW** in 1996:

- Low-yield germplasm
- Yellowleaf and stem rust
- Other foliar diseases
- Soil fertility and conservation problems
- Weeds
- Drought
- Tillage problems

Progress, although slow, is being made in genetic engineering to improve wheat by developing such characteristics as drought tolerance and disease resistance. Most biotechnology research on wheat is located in public-sector advanced universities and research institutes, and is directed toward first understanding the complexities of the wheat plant with the goal of eventually using biotechnology to develop transgenic wheat with unique desirable traits.

One reason that transgenic research on wheat has progressed so slowly is that the private sector considers wheat to be a low-value crop compared to other major crops such as cotton, rice, and soybeans. This is partly due to the fact that wheat is self-pollinated crop and farmers can therefore replant their own seed instead of having to buy improved seed year after year. An additional technical reason is that the genome of wheat is 10 to 20 times larger than that of crops like cotton or rice. Improving wheat by biotechnology is therefore a far more complex and time-consuming challenge. Among American universities, Kansas State, Cornell, Oklahoma State, and Texas A&M are working on wheat at the molecular level. Some of the main targets for genetic engineering research in wheat are control of pre-harvest sprouting; enhanced processing and nutritional quality; reduced mycotoxin contamination; heat and cold tolerance; salinity tolerance; aluminum tolerance; drought tolerance, and resistance to insects and fungal diseases.

### *Current biotechnology products and projects*

- **CLEARFIELD™ wheat *(American Cyanamid, New Jersey, USA*).** American Cyanamid is cooperating with universities, public and private laboratories and seed companies to develop wheat varieties tolerant to imidazolinone herbicides. Imidazolinone herbicides are flexible, environmentally friendly and provide contact and residual control of weeds common to wheat production, including ones not controlled by currently registered wheat herbicides.
- **Insect resistance (*Mycogen Corp, part of Dow AgroSciences, Indianapolis, USA).*** This wheat expresses a Bt toxin providing resistance to various caterpillar and beetle pests.
- **Genetic markers for insect resistance (*Texas A&M University).*** This research focuses on tagging and mapping DNA markers on the wheat chromosome to locate the genetic basis of traits that are of particular interest to Texas wheat growers. At this stage, DNA markers have been identified on the wheat chromosome for Russian wheat aphid (RWA) resistance and for greenbug resistance. This knowledge could eventually lead the way to RWA- and greenbug-resistant wheat varieties. Work has also begun on tolerance to wheat leaf rust.
- **Resistance to major fungal pathogens (*CIMMYT*).** Antifungal proteins from barley are currently being inserted into wheat to investigate resistance to some of the major fungal pathogens.
- **Wheat genomics (*Consortium of U.S. universities*).** The long-term goal of this project is to decipher the chromosomal location and biological function of all genes in the wheat (*Triticum* spp.) genomes. This knowledge will greatly enhance our understanding of the biology of the wheat plant and create a new paradigm for the improvement of this exceedingly important crop.

#### Prospects

Transformation of wheat with useful traits for Africa is still probably several years away, due to the difficulties of the system. However, important progress is being made using genetic markers for traits such as disease and drought resistance. This, and the recent publishing of the rice genome, should greatly speed up conventional breeding of wheat for the region.

# Potato (*Solanum tuberosum*)

## Background

The ASARECA network responsible for potato and sweet potato is **PRAPACE** (the Potato and Sweet Potato Collaborative Research in Eastern and Central Africa). There is little data on the production of potato and sweet potato in PRAPACE member countries. Both crops are grown on a small scale by millions of small farmers, and are either consumed in the household or sold through informal, unregulated markets. For potato, the total area reported is 308,000 ha, and the total production is estimated at 1.7 million tons. This represents approximately 40% of the potato production in sub-Saharan Africa. In Africa as a whole the most important producing countries are South Africa, Malawi, Cameroon and Nigeria. Within PRAPACE countries the production is concentrated in densely populated highland areas over 2,000 meters above sea level. The largest area is planted in Kenya, where the reported average yields of 2.7 t/ha are far below developed country farm-level yields of between 7 and 15 t/ha. Potatoes are consumed in the area of production and in cities and towns that provide a growing market. Average per capita consumption varies; over large areas of lowland, potatoes are rarely consumed, whereas in some highland areas consumption can be as high as 80-90 kilos per person per year, and three times this amount in urban areas.

Potato has become a major cash crop in the highlands above 1,800 m and is a highly preferred food in urban areas. High yields in a short growing season and high energy and protein production make potato an attractive source of food and improved nutrition. The nutrient value of potatoes, including vitamin C, is high, and they are particularly useful as a source of energy and protein. Potatoes are increasingly consumed in the form of processed foods such as frozen French fries and potato chips. Important industrial uses include processing and manufacturing of starch and alcohol.

Potatoes also provide important on-farm and off-farm employment and critical income to poor households. Although there are some large-scale farmers, the bulk of potato marketing is through private traders in domestic markets. A few hundred tons are marketed across the borders of Kenya, Uganda, Burundi, Rwanda and Congo.

Worldwide, potato is the fourth most important crop in developing countries after rice, wheat, and maize. The main climatic constraint limiting area expansion for the potato is temperature -- potatoes respond positively to cooler temperatures. The main biotic constraints for potato are late blight, bacterial wilt disease, viruses, and potato tuber moth. Researchers estimate that developing country farmers spend $700 million annually to control such pests. Potato's susceptibility to these pests and diseases makes it number two crop in agricultural pesticide use worldwide following cotton. In the case of late blight (*Phytophthora infestans*) alone, the International Potato Centre (Centro Internacional de Papa, or CIP) has estimated that the combined cost of crop losses and chemicals applied exceed $3.0 billion per annum. Potato production in the developed countries remains fairly static, with supply matching demand, whereas during the last 30 years an increasing proportion of the global crop has been produced in developing countries, rising from approximately 11% in the 1960s to more than 30% in the 1990s.

Constraints to potato production—and, consequently, research priorities of PRAPACE—include:

- late blight (*Phytopthora infestans*)
- bacterial wilt (*Ralstonia solanacearum*)
- viruses
- potato tuber moth (*Phthorimaea operculella*)
- low soil fertility
- storage problems

For both potato and sweet potato, the lack of clean (virus-free) quality seed/planting material from improved varieties is also a major problem.

The CIP has the global mandate for research into potato and sweet potato. Over the past 20 years it has led a global effort to develop pest control practices. The potato has responded relatively well to research, and plant breeding continues to result in significant improvements in the crop, especially for developing countries. Virology research in the potato has advanced greatly, and the safe movement of germplasm is now practical. However, the adoption of improved potato varieties is often delayed by the absence of local seed or multiplication systems.

The European or Irish potato has a relatively narrow genetic base, and the system of clonal reproduction by tubers renders it extremely susceptible to diseases and pests, as is evidenced by the Irish potato famine in the 1840s. Serious problems have also been caused for the industry by potato cyst nematodes. Although breeders have begun to incorporate some resistance into some types of the nematode into some modern cultivars, this pest remains effectively controlled only by routine application of highly toxic nematicides.

Conventional breeding of potato takes much time and effort. Hybridization of cultivated potato with even its closest relatives usually requires several generations of backcrossing and selection to restore the yield and quality of a modern cultivar. More importantly, it risks the introgression of undesirable traits, particularly high levels of toxic glycoalkaloid compounds in the tubers. Because the European potato is a tetraploid and suffers from marked inbreeding depression, it is unlikely that classical breeding will be able to combine all desirable traits into a single clone. The use of molecular markers is now enabling the construction of genetic linkage maps and the means to locate genes and quantitative trait loci (QTL), which are useful contributions to potato breeding efforts. A major advantage of genetic modification of potato is that it can allow the transfer of specific genes that confer resistance, as opposed to the entire genomes of these wild varieties that have otherwise undesirable qualities.

Potato was the first food crop to be genetically engineered, and since the first introduction of this technology at CIP in 1985, thousands of transgenic potato clones have been produced. For example, more than 10 developing-country potato varieties have been engineered with resistance to the potato tuber moth, an extremely serious pest both pre- and post-harvest in many developing countries. This research has been highly successful in generating a technology that promises to reduce or eliminate crop losses caused by this pest. CIP estimates that roughly $500 million in annual losses can be attributed to the potato tuber moth alone.

Substantial commercial acreages of transgenic potatoes are already being grown in North America. The first of these, "Russet Burbank New Leaf," is a genetically modified form of an old, very disease-susceptible, but popular cultivar. The New Leaf transgenic variant has been transformed with a Bt toxin gene that renders it resistant to Colorado potato beetle. A strategy now being pursued for this and other insect pests is to “pyramid” several different Bt toxin genes into the potato to reduce the selection pressure for resistance in the pest population.

In addition to insect resistance using the Bt toxin approach, it has also been possible to genetically modify potatoes with resistance to several of the common viruses. This is based on transforming the plant with the coat protein or other genes of those viruses. Some potatoes already possess major dominant genes conferring extreme resistance to the common viruses, Potato Virus X (PVX) and Potato Virus Y (PVY). These genes have been introgressed by classical breeding from wild species and primitive forms, but very few cultivars possess them and their impact has been small. However, these genes have now either been mapped or are close to being mapped, and transforming susceptible cultivars with these genes in the future seems a likely possibility. PVY is a particularly serious virus that currently can only be controlled by frequent, routine applications of insecticides to kill its vector (aphids), which is not always successful. This would therefore be a good target for genetic transformation.

Although most progress in protecting potatoes by genetic modification so far has been made against insects and viruses, advances are being made in closely related species (e.g., tomato) against fungi, bacteria and nematodes. In addition, attention is now being focused on quality traits such as starch composition, which affects fat absorption on frying. Whether these characteristics would be given as high a level of importance in the developing world is uncertain.

PRAPACE has links with CIP and other ARIs that are actively using molecular tools for germplasm characterization and pathogen detection and characterization.

### *Current biotechnology products and projects*

- **Resistance to potato tuber moth (*Dr. David Douches, Michigan State University, East Lansing)*.** The potato tuber moth (*Phthorimaea operculella*) is a potato pest in several countries in Africa. In some cases, it is the single most significant constraint to potato production. The lack of adequate cold storage facilities makes this technology very relevant to a number of African countries, as damage can result in total loss of stored potatoes. Field tests of several transgenic lines are ongoing in Egypt (four years) and planned shortly for South Africa and Indonesia.
- **Resistance to potato tuber moth (*Aziz Lagnaoui, International Potato Center, Peru*).** CIP has developed transgenic potato plants that are resistant to the potato tuber moth and that express the Bt crystal protein (Cry IA), but other Cry genes may be added in the near future. The transgenic potatoes are currently being tested in Peru and plans are underway for testing next season in Egypt. The material is available for testing in countries with appropriate biosafety regulations.
- **Biological control of bacterial wilt disease of potato (*Dr. Julian Smith, CABI Bioscience, UK*).** CABI Bioscience has developed a genetically modified non-

pathogenic strain of the bacterium *Pseudomonas* that can be applied to the soil to control bacterial wilt of potato. Field trials are currently ongoing in South Africa and planned in Kenya.

- **Resistance to nematodes and insects (*Prof. H. Atkinson, University of Leeds, UK*).** An effective transgenic defense system against the plant pathogenic nematodes *Naccobus aberrans* and *Globodera* spp is being adapted for Bolivia and other Andean regions. Nematode control will benefit agricultural development by reducing yield loss and traditional dependence on control procedures such as fallowing. Further plant transformation will be directed at native cultivars, particularly those that already possess partial resistance against nematodes. Contained trials are anticipated shortly. (DFID funding.)
- **Resistance to PVX, PVY and PLRV (*ARC-Roodeplaat, South Africa*).** Efforts are underway to transform potatoes with coat protein-mediated resistance. Several transgenic lines resistant to for PLRV have been regenerated. *In vitro* infection of the plants made it possible to test the transgenic lines for resistance to viral diseases in the glasshouse. The first field trial of transgenic potatoes in Africa is currently underway at Roodeplaat. Work on the PVY and PVX transgenic lines is still continuing.
- **Reduced-alkaloid potatoes (Dr. *William R. Belknap, USDA ARS, USA*).** Genes that block the bitter compounds (glycoalkaloids) that are naturally present in potatoes have been inserted into potato and have reduced alkaloid levels by 40-60%. Besides being useful in itself, this may also enable potato breeders to use insect- or disease-resistant traits from native tubers that would otherwise be removed from breeding programs because of their high glycoalkaloid levels. The Agricultural Research Service, the USDA's chief research agency, has a patent for the anti-glycoalkaloid techniques and has licensed the technology to Small Potatoes, Inc., which has agreed to provide the technology to developing countries in the Andean region. Field-testing is planned at CIP, Peru.
- **NewLeaf® insect-protected potato (*Monsanto*).** Introduced in 1995, the NewLeaf® Potato was the first commercial crop to be protected against insect pests through biotechnology. The NewLeaf® Potato carries a Bt gene that confers resistance to the Colorado potato beetle.
- **High-solids potato (*Monsanto*)**. Monsanto has developed a higher-solids (starch content) potato by introducing a starch-producing gene from a soil bacterium into a potato plant. With the reduction in the percentage of water in the genetically improved potato, less oil is absorbed during processing, resulting in a reduction of cooking time and costs, better-tasting french fries and an economic benefit to the processor. This product is currently in the developmental stage.
- **NewLeaf® Plus (*Monsanto*).** These are potatoes with resistance to both insects and viruses – specifically Colorado potato beetle and potato leaf roll virus. This product is currently under development.
- **New-Leaf® Y Insect- and Virus-Protected potatoes (*Monsanto*).** Another potato that is currently in development combines resistance to Colorado potato beetle and Potato Virus Y.

### Prospects

Potato transformation is now developing very rapidly and there are already many varieties that might be applicable for the ASARECA region. Potato tuber moth resistance and virus resistance are the two most obvious traits of importance. Work on transgenic resistance to fungal diseases (in particular, late blight) is also ongoing in many regions. Due to the high variability of this pathogen, it would be useful for ASARECA to be involved in the early stages of such work to ensure that any resistance developed includes isolates that are prevalent in the region. Overall there are numerous groups working on constraints of importance to PRAPACE. Collaborations with these ARIs should be explored should ASARECA classify potato biotechnology as a priority research area.

# Sweet Potato (*Ipomoea batatas* LAM.)

## Background

The ASARECA network responsible for sweet potato is also **PRAPACE** (the Potato and Sweet Potato Collaborative Research in Eastern and Central Africa). There is little data on the production of sweet potato in PRAPACE member countries. Sweet potato is grown on a small scale by millions of small farmers, and is either consumed in the household or sold through informal, unregulated markets.

Worldwide, sweet potato is considered to be a versatile and under-exploited food crop. The total area of production reported is 1.3 million ha, and total production is 5.7 million tons. It currently ranks as the fifth most important food crop on a fresh-weight basis in developing countries after rice, wheat, maize and cassava, with more than 133 million tons in annual production. Sweet potato is cultivated in over 100 developing countries and ranks among the five most important food crops in over 50. Average yields in several ASARECA countries are well below the average (15 t/ha) for developing countries as a whole, and these in turn are well below the current yield potential. Rapid improvements in productivity of the crop are considered feasible, with relatively less investment in research and extension than some other crops.

Sweet potato is a food security crop grown mostly on small plots of land. The crop is important in the densely populated, mid-elevation regions in the countries surrounding Lake Victoria: i.e., Uganda, Rwanda, Burundi, eastern DR Congo, northwest Tanzania and Western Kenya. It is also grown on a smaller scale in South Africa. Sweet potato has received increased attention in recent years because it can be grown in soils of limited fertility, is relatively drought-tolerant, provides good ground cover, and is usually cultivated without pesticide or fertilizer. Planting and harvest periods are more flexible than those of maize and other grains, and it has become even more important in areas where African cassava mosaic virus (ACMV) and black Sigatoka of banana have devastated the production of these food crops.

Per capita sweet potato consumption in Rwanda is estimated at 160kg/yr; Burundi, 102 kg/yr; and Uganda 85kg/yr. Sweet potato consumption also varies *within* countries, by regions, by time of year and by income group. In northeast Uganda, one of the poorest parts of that country, sweet potato becomes a seasonal staple during the dry season when supplies of most other foodstuffs are exhausted. Even under such circumstances the potential importance of the crop may be underestimated. Average yields of 5t/ha for sweet potato in Africa (FAO) are the lowest of any developing country region—and less than one-third of yields in Asia—suggesting considerable scope for improvement.

Sweet potato forms an important source of calories in the diet, and the orange-fleshed varieties also provide a significant portion of the requirement of vitamin A intake, which is particularly important in areas with endemic malaria. In addition, sweet potato provides ascorbic acid and the amino acid lysine, which is absent in common foods such as rice. For the most part, small-scale farmers sell sweet potato in small quantities at local markets, providing them with a source of ready cash. The crop is also sold in urban markets, but the storage root deteriorates rapidly after harvest, so losses and costs are high. Home or village-level processing of sweet potato is increasing. In many areas serious attacks by weevils limit the length of time the roots can be left in the ground, and farmers harvest, chip and sun-dry the roots to preserve and store the crop. Farm households have long made processed products from sweet potato -- including starch, noodles, candy, desserts, and flour -- to extend the availability, diversify the use, and increase the value added for to the crop. There is significant potential for new uses of sweet potato flour as an ingredient in the production of a large number of products that are usually made from imported wheat.

Sweet potato is relatively intractable to conventional breeding and poses many challenges to sexual hybridization. It is a hexaploid and has problems such as pollen sterility, incompatibility and poor seed germination. Biotechnological tools have become especially relevant to sweet potato, as these techniques enable rapid incorporation of specific traits into pre-adapted cultivars and complement conventional approaches to crop improvement.

Regional production constraints for sweet potato include important virus diseases -- e.g., sweet potato feathery mottle virus (FMV), stem blight and other diseases that attack the roots. The African sweet potato weevils, *Cylas puncticollis* and *C. brunneus*, are the most destructive pests of sweet potato in sub-Saharan Africa. Weevil damage renders them unfit for human and animal consumption and secondary compounds such as terpenoids produced in response to weevil feeding make even slightly damaged roots unpalatable. Crop losses due to weevil damage range from 20% to 100%, and losses are more severe in the dry season and during periods of drought. Little or no resistance to this pest is available in sweet potato germplasm. Several groups are working on the development of transgenic sweet potato with resistance to weevil using *Coleopteran*-specific Bt genes.

In other regions of the world where a different weevil occurs (*Cylas formicarius*), control of the pest is based on cultural practices, the use of pheromones and bio-insecticides. In Africa, pheromones have not been effective against the sweet potato weevil, and bio-insecticides are not generally available or affordable. The ideal solution for a pest such as the sweet potato weevil would be to plant resistant varieties. Unfortunately, none have been developed, despite efforts to select resistant clones in different parts of the world. Even where "less susceptible" varieties exist, they do not perform well under high pest population levels. The most promising direction for research is therefore to develop true resistant varieties through the introduction of exogenous genes, such as the Bt gene, in order to confer resistance in sweet potato.

### *Current biotechnology products and projects*

- **Resistance to feathery mottle virus (*Kenya Agricultural Research Institute, Kenya; Monsanto, USA; ABSP, Michigan State University, USA*)**. Sweet potato feathery mottle virus (SPFMV) is a serious constraint to sweet potato production in Africa. Different sweet potato varieties (an African and a U.S. variety) have been transformed with the sweet potato feathery mottle virus coat-protein and have been shown to be expressing the transgene. Monsanto has donated its virus-resistance technology royalty-free for use in sweet potato in Africa. Biosafety approval was granted in Kenya, and field testing began in 2000.

- **Resistance to feathery mottle virus (*C. S. Prakash, Tuskegee University, USA, and D. R. Beachy, Danforth Institute, USA*).** Coat protein and antisense RNA genes of the SPFMV have been introduced into sweet potato varieties and are being tested for their resistance to the virus.
- **Enhanced protein content and quality (*C. S. Prakash, Tuskegee University, USA)*.** Sweet potato has been genetically engineered for increased storage protein (asp-1), causing a 3- to 5-fold increase in total protein content. Tubers also exhibit a proportional increase in levels of essential amino acids such as methionine, threonine, isoleucine, lysine and tryptophan. Material has been field tested in the US (at Tuskegee) and in the US Virgin Islands
- **Resistance to fungal diseases (*C. S. Prakash, Tuskegee University, USA, and Dr. Jesse Jaynes, Demeter Technologies, USA).*** Sweet potato varieties have been transformed with synthetic lytic peptide genes that code for peptides with antimicrobial activity. These have shown promise against bacterial and fungal diseases in potato and tobacco.
- **Resistance to sweet potato weevil (*Dr. Dapeng Zhang, International Potato Center, Peru*).** Transgenic plants expressing exotic proteinase inhibitors and Bt-proteins and resistant to sweet potato weevil (*Cylas* spp.) have been produced. University of Missouri and Monsanto Company are currently screening Bt proteins. Transgenic plants with soybean proteinase inhibitors will be field-tested within a year at CIP experimental facilities. These transgenic varieties could be critical to maintaining an economically important crop that is otherwise threatened by sweet potato weevil throughout the region.

### Prospects

The same approach used to develop resistance to Colorado potato beetle and potato tuber moth in potato can easily be adapted for African varieties of sweet potato. Improving viral resistance and protein content could also provide immediate significant benefits to small farmers in the region.

## Coffee (*Coffea* spp) and Cocoa (*Theobroma cacao*)

### Background

The ASARECA network responsible for coffee is **CORNET** (Coffee Research Network). Coffee is the most important cash crop in the ASARECA region. It is produced and exported from eight member countries, and approximately 10 million rural families (mainly smallholders) in the Central and Eastern Africa region rely on income from coffee. Coffee exports earn approximately 85% of the foreign exchange for ASARECA countries. CORNET is a relatively new ASARECA network, having been proposed in 1998.

Coffee is the world's second largest traded commodity and one on which many countries rely to obtain foreign exchange. From the commercial point of view, only two coffee species are cultivated extensively: *C. arabica* (Arabica) and *C. canephora* (Robusta), although some other species are grown for local consumption. *C. arabica* is native to the highlands of Ethiopia and was brought from tropical Africa to Latin America in the early 18$^{th}$ century. Arabica coffee is grown at altitudes of 1,000-

2,000m and accounts for about 75% of commercial world coffee, including all coffee production in Latin America. This species is also produced in Ethiopia and Kenya. *C. canephora* has a very wide geographic distribution, extending from the western to the central tropical and subtropical regions of the African continent, including parts of Uganda and DR Congo. In 1999 total world production of coffee was 6.5 million MT 1.2 million MT of which was produced in Africa. Within Africa, Cote d'Ivoire is the largest producer (365,000 MT), followed by Ethiopia (232,000 MT), and Uganda (198,000 MT). Kenya, Madagascar and Tanzania are also important producers, each producing approximately 50,000 MT.

Constraints to coffee production in the ASARECA region include low soil fertility, and several important fungal diseases (coffee berry disease caused by *Colletotrichum coffeanum*, rust caused by *Hemilea vastatrix*, and a bark disease caused by *Fusarium* spp.). Insect pests include scale insects, mealybugs, and the coffee berry borer. Nematodes such as *Meloidogyne* and *Pratylenchus* can also be a serious problem.

Coffee breeding by conventional methods is a long process, and traditional methods of improvement are slow, taking more than 30 years to produce a new cultivar. This is partly due to the inherent problems involved in breeding a perennial crop species with a long life cycle. The introduction of *in vitro* propagation techniques has proved to be a great advantage in coffee breeding in recent years and has also allowed manipulation of the coffee plant at the cellular and molecular levels. Such techniques include protoplast culture, culture of zygotic embryos and anther/pollen culture. Genetic transformation of coffee has potential to greatly speed up these processes (Carneiro, 1999).

Cocoa (*Theobromoa cacao L*) is not an ASARECA-priority crop. However, it does have a number of similarities to coffee in terms of the use of biotechnology for crop improvement. Cocoa breeding by conventional methods is a long process, and traditional methods of improvement are slow. This is again partly due to the inherent problems involved in breeding a perennial crop species with a long life cycle.

There are a number of groups supporting research on cocoa. They are the International Permanent Working Group for Pests and Diseases of Cocoa (INCOPED), the International Cocoa Organization (ICCO), and the American Cocoa Research Institute (ACRI). INCOPED was formed to meet the specific needs and interests of cocoa entomologists and pathologists, and has had up to 33 members, representing 14 countries, attend their semi-annual meetings. This group has not been involved in biotechnology research in any significant way.

The ICCO comprises 40 countries and one intergovernmental organization, representing over 80% of the world cocoa production and approximately 70% of the world cocoa consumption. No ASARECA countries are members. Among other goals of ICCO is the promotion of scientific research and development in cocoa. One of the major research efforts is the conservation and utilization of cocoa germplasm, including the cloning of germplasm associated with performance trials, population breeding programs, and development of improved germplasm.

ACRI is the research arm of the Chocolate Manufacturers Association of America and is devoted to research in all scientific areas related to cocoa and chocolate. ACRI has a Biotechnology Working Group that monitors, generates, and supports research in the biotechnology of cacao to improve its production and quality, particularly through the Biotechnology Program at Pennsylvania State University. Researchers at Penn State have produced a method of clonal propagation (somatic embryogenesis), and have begun a long-term field test of cloned cocoa plants in St. Lucia in the West Indies. They have also begun a genetic engineering research program to develop cocoa with resistance to disease and pests, including the cocoa pod borer, the myrid, witch's broom, pod rot and cocoa swollen shoot virus. This work is preliminary.

### *Current biotechnology products and projects*

- **Tissue culture methodologies *(Agricultural Research Centre, South Africa*).** The Institute of Tropical and Sub-Tropical Crops has developed a system for the rapid multiplication of coffee. The improvement with coffee cuttings is dramatic. In *Robusta* coffee selections, rooting was increased by 312% compared to conventional cuttings. The commercial application of this technique is now being investigated. Potentially this could make a huge difference to coffee production in Africa.
- **Development of decaffeinated coffee (*University of Hawaii*).** Researchers at the University of Hawaii have developed transgenic coffee containing the antisense gene for the enzyme xanthosine-N7-methyl transferase, the first enzyme in the pathway to caffeine synthesis. They cloned the gene encoding this enzyme, and used *Agrobacterium*-mediated transformation to insert an antisense version into *Arabica* coffee cells growing in tissue culture. Transgenic callus was analyzed, and some lines were found to have only 2% of the normal level of caffeine found in regular plants. Thus, expression of the caffeine gene appears to have been silenced by the introduction of the antisense gene. In another approach, Dr. Chifumi Nagai at the Hawaii Agricultural Research Center is using a gene gun to produce transgenic plants. The new coffee plants have only been grown in the laboratory, so it will be years before commercial crops will produce naturally decaffeinated coffee.
- **CENICAFE (*Colombia*).** Through its research branch, CENICAFE, the Federation of Coffee Growers of Colombia has supported Cornell University to develop technology for genetic transformation of the coffee plant, cloning of gene promoters from coffee, cloning of genes for insect-inhibiting proteins, and sequencing of the coffee genome.

### Prospects

The first reports of coffee transformation appeared in 1991, but since then progress has been slow. Current research goals for groups involved in coffee biotechnology include pest and disease resistance, herbicide resistance, resistance to low temperatures, and plants low in caffeine. No transgenic coffee varieties have so far been released. However, improvements in tissue culture methodology for both coffee and cocoa may be available to farmers in the near term.

# Cotton (*Gossypium* spp.)

### Background

There is no ASARECA network specifically focused on cotton, even though it is identified as a priority crop for the region**.** Cotton is mostly grown in tropical and sub-tropical climates and is one of the most ancient cultivated crops. The American continents are the largest producers, followed by Asia and Africa. The United States is the single largest producer, but cotton is also extremely important to the economies of many developing nations. World production of cotton lint in 1999 was 18.3 million MT, and of this total 1.6 million MT was produced in Africa.

Four species of the genus *Gossypium* are known as cotton, which is grown primarily for the seed hairs that are made into textiles. A member of the Malvaceae, *Gossypium* consists of 39 species, four of which are generally cultivated. The most commonly cultivated species is *G. hirsutum* L. Other cultivated species are *G. arboreum* L., *G. barbadense* L., and *G. herbaceum* L.

Cotton is a small shrub or tree that produces a fruit or *boll* containing seeds bearing the cotton lint. It is grown under a wide range of climatic conditions, both rainfed and with irrigation. The major use of cotton lint is for the production of a variety of fabrics and related products. The seeds are used to produce a high-quality edible oil. The cotton seed cake or press cake remaining after oil extraction is used as an animal feed, as it has high protein content.

Among the most important diseases of cotton are two fungal wilt diseases (caused by *Verticillium dahliae* and *Fusarium oxysporum* f.sp. *vasinfectum*); leaf rust (*Puccinia cacabata*), a leaf curl disease caused by a whitefly-transmitted virus; and various boll rots caused by many species of fungi but exacerbated by insect attack. The main insect pest of cotton is the larva of *Helicoverpa armigera*. Much of the biotechnology focus in cotton, both in the public and private sector, has been on producing herbicide-resistant and insect-resistant varieties.

### *Current biotechnology products and projects*

- **Bollgard® Insect-Protected Cotton (*Monsanto*).** Introduced in 1996, cotton with Monsanto's Bollgard Bt gene is protected against cotton bollworms, pink bollworms and tobacco budworms.
- **Bollgard with BXN Cotton (*Calgene, LLC, unit of Monsanto*).** These cotton plants with insect and herbicide resistance require less chemical herbicide and insecticide, lowering grower input costs and achieving greater crop yield.
- **Roundup® Ready Cotton (*Monsanto*).** Approved in 1996, Roundup Ready® cotton tolerates both topical and post-directed applications of Roundup® herbicide.
- **Genetically Engineered Cotton Fiber (*Agracetus, USA*).** This biotech product is genetically engineered to enhance fiber performance, reduce dye-shop pollution and improve textile-manufacturing efficiency. Available within 6 years.
- **Second-Generation Bollgard® Insect-Protected Cotton (*Monsanto*).** Cotton similar to the original Bollgard cotton, but using a different Bt gene mode of action to help growers manage insect resistance concerns. Available within 6 years.

### Prospects

Small farmers in regions of South Africa are already growing transgenic insect-resistant cotton, and field trials have just begun in Zimbabwe. Preliminary results show that farmers quickly and eagerly adopt the technology, and that pesticide applications have been significantly reduced compared with nontransgenic crops.

Given the current high levels of insecticide application to cotton, the advantages of this technology to the environment are obvious.

# Rice (*Oryza sativa, Oryza glaberrima*)

## Background

The ASARECA network responsible for rice is **ECSARRN** (The Eastern, Central and Southern Africa Rice Research Network). Rice is grown and consumed in most countries of Eastern, Central and Southern Africa. However, despite increased production in the region since 1990, national self-sufficiency has rarely been reached and substantial unsatisfied demand for rice still exists. By the mid-1990s, countries in the region (including South Africa) imported over 1 million tons of rice valued at US $400 million. Imports provided over one-third of the rice consumed.

Madagascar is the major rice producer in the region, having 1.2 million ha in rice and total rough rice (paddy) production reaching 2.5 million tons per year. Tanzania is the next highest producer (550,000 tons), followed by Congo (436,000 tons). Other rice-producing countries with the potential to significantly increase surface area and/or yield include Mozambique, Uganda, Rwanda, Burundi, Malawi, Zambia and Kenya. Rice production is not keeping up with population growth and increased demand, resulting in increasing imports. Given the recent importation figures in countries such as Kenya and South Africa, as well as the changing consumption patterns of urban populations in Africa, rice has the potential to be an important commercial crop in the region.

Globally, rice is the most important crop in terms of its contribution to human diet and value of production. Rice provides between 35% and 80% of the calories consumed by 3.3 billion people in Asia, and 8% of food energy for 1 billion people in sub-Saharan Africa, Latin America and the Caribbean. However, although rice protein ranks high in nutritional quality among cereals, actual protein content is modest. Rice provides minerals, vitamins, and fiber, but milling reduces all constituents except carbohydrates.

Cultivated rice belongs to two species, *Oryza sativa* (more widely used) and *Oryza glaberrima* -- an African rice. The two main strains of *O. sativa* are japonica and indica. The differences between these two evolved both geographically and culturally over thousands of years. During the 1960s, CGIAR scientists improved rice varieties to produce IR8, the first of the modern, high-yielding "miracle rice" varieties. IR8, which doubled rice production yields, was the catalyst for the Green Revolution in rice. Today, more than 60% of the world's rice fields are planted with varieties with origins in the work of CGIAR scientists and their partners. A later variety, IR36 -- with the ability to withstand a wide range of pests -- has been planted on more than 27.5 million acres, setting a world record as the only single food crop to have been planted so widely.

Rice-growing environments in the ASARECA regions are highly diverse. Most rice is grown under rainfed conditions, both lowland and upland ecosystems, making direct transfer of agronomic technology from West Africa, Asia and Latin America difficult. Despite some germplasm transfer, local varieties remain the most widely cultivated. These varieties, though well adapted to their environments and the taste preferences of consumers, are low-yielding. Major technical constraints to production in the region are:

- o inadequate land preparation
- o weed control problems
- o low soil fertility
- o poor water management
- o insect pests
- o disease, e.g., blast, rice yellow mottle virus (RYMV)
- o *Striga*

All these production constraints are anticipated to increase if regional production intensifies.

Three CGIAR research centers currently focus on rice research: the International Rice Research Institute (IRRI) in the Philippines, the West Africa Rice Development Association (WARDA) in Cote d'Ivoire, and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia. The three research centers collaborate to improve yield potential, develop hybrid rice for the tropics, improve nitrogen-use efficiency in rainfed systems, and combat pests, diseases, and weeds.

Sources of resistance to some rice diseases (blast and bacterial blight) have been identified within cultivated rice germplasm, and improved germplasm with resistance has been developed. However, sources of resistance to other diseases (such as sheath blight) have not been found, and there is little resistance available to several of the important virus diseases such as tungro.

Molecular biological techniques such as embryo rescue and anther culture have been used for many years in rice-breeding efforts, and considerable progress has been made. Embryo rescue enables breeders to attempt wide crosses between varieties that could not be hybridized before; anther culture allows faster stabilization of breeding lines. Molecular techniques have helped to accelerate traditional breeding, streamline germplasm management and assess population structures in pests and pathogens through DNA fingerprinting.

Molecular marker analysis is also being used extensively to identify and understand the variability of pathogen populations. This information can then be used in screening programs aimed at developing resistant genotypes. Perhaps the most significant recent advance in rice molecular biology is the publication of the genomic map of rice by Monsanto. Such a genetic map is of great value in understanding genome organization, and in cloning of other agriculturally important genes. Rice also serves as a model for genome research in monocotyledons because of its relatively small genome size, excellent germplasm collection, and relatively well-developed genetic maps. Comparative genome mapping in rice, maize, wheat, barley and sorghum is also now proceeding rapidly.

In recent years, considerable advances have also been made in the production of transgenic rice varieties by the introduction of genes from bacteria, fungi, animals and other plant species. This has allowed plant breeders to accomplish objectives considered impossible a decade ago. Transformation of rice is now possible through several techniques, such as electroporation, protoplast uptake, and biolistic and *Agrobacterium*-mediated methods. This has proved effective for japonica as well as indica varieties.

Now that substantial progress has been made on transformation protocols for rice, numerous rice lines with useful foreign genes have been produced. As in other crops, the use of Bt genes is a major strategy for insect resistance, and several insecticidal toxin genes from *Bacillus thuringiensis* (Bt) have been transferred to rice. Plants containing Bt genes have been evaluated in greenhouses and have shown substantial resistance to caterpillar pests such as stem borers and leafhoppers. Genes encoding proteinase inhibitors from cowpea, soybean, and potato have also been transferred to rice. They show enhanced resistance to stem borers in field tests conducted in China. Rice has also been transformed with a lectin gene from the snowdrop plant, a protein known to be toxic to the brown planthopper and green leafhopper, but as yet no resistant plants have been identified. Further work remains to be done with all these insecticidal genes in order to determine the right doses and combinations of toxins for particular local pests, the stability of toxin production over several generations, and the performance of the plants under field conditions.

In addition to research on insect resistance, various strategies are being investigated for virus resistance. For example, coat protein–mediated resistance is being investigated as a strategy for resistance to rice tungro virus. Herbicide tolerance is another major area of research, because direct seeding of rice can lead to serious competition with weeds. Fungal diseases are possibly the least researched area, but recently, transgenic rice has been obtained with resistance to sheath blight, caused by *Rhizoctonia solani.* Plants are currently undergoing testing at IRRI.

For a full list of transgenic rices carrying agronomically important genes for resistance to stem borer, virus tolerance, resistance to fungal pathogens and herbicide tolerance, see Khush and Bhar (1998, Table 9).

In addition to the use of biotechnology to combat biotic constraints, considerable research effort is focused on breeding for abiotic stress tolerance, particularly salt tolerance, and tolerance of heavy metal ions and oxidative stress. Another research goal in rice and many other crops is the development of varieties that are able to fix their own nitrogen. Transgenic varieties with these traits are still, however, many years from development. A recent high-profile development has been the transformation of rice for better nutrition, with genes that enhance beta-carotene and iron production (see below).

### *Current biotechnology products and projects*

- **Liberty-Link® Herbicide-Tolerant Rice (*AgrEvo, Inc.*).** Approved for commercial sale by the USDA in 1999, this rice variety is tolerant to Phosphinothricin (PPT) herbicide, specifically glufosinate ammonium. It is expected to be launched commercially in 2001.
- **Roundup Ready Rice (*Monsanto, USA*).** Roundup Ready rice varieties are currently being developed by Monsanto. Instead of herbicide inactivation, this gene is responsible for the synthesis of a target biosynthetic enzyme that is unaffected by the herbicide. At this point, these lines are in the early phases of development; early material is being screened to try to find lines that are marketable, and it is hoped that these lines will be released commercially by 2003.
- **Metabolically modified rice (*Nagoya University, National Institute of Agrobiological Resources, Japan*).** Researchers at these two institutions recently demonstrated that new rice strains could boost photosynthesis and grain yield by up to 35%. These researchers altered the normal $C_3$-photosynthesis

pathway in rice to a $C_4$-photosynthesis pathway, similar to that in maize and sugarcane. This was done using an *Agrobacterium*-mediated transformation system and independently introducing three maize genes encoding the $C_4$-photosynthetic pathway enzymes. Preliminary field trials in China and Korea show a 10-30% and 30-35% increase in grain yield, respectively, for two of the genes transformed in the rice plants.

- **High-vitamin A and -iron rice (*Swiss Federal Institute of Technology's Institute for Plant Sciences; Rockefeller Foundation*).** In a major advance in global nutrition, researchers have recently created a strain of genetically altered rice to combat vitamin A deficiency, the world's leading cause of blindness and a malaise that affects as many as 250 million children. The new "golden rice" contains three transplanted genes that allow plants to produce rice kernels containing beta-carotene, a compound that is converted to vitamin A within the human body. The same research team is also completing work on another genetically modified rice strain with increased iron content. Iron-deficiency anemia, the world's worst nutrition disorder, affects nearly 2 billion people. IRRI is now working on putting these traits into commercially useful rice strains. Once researchers produce crops of viable seed rice, the institute will offer the new rice free to any nation that wants it.
- **Resistance to stem borers (*IRRI, the Philippines*).** IRRI, as well as researchers from several advanced laboratories in Japan and Europe, has developed rice with resistance to yellow stem borer and striped stem borer via expression of Bt proteins. While demonstrating promising levels of resistance, extensive field trials in multiple countries have yet to be carried out.
- **Rice yellow mottle virus resistance (*Dr. M. Koyama, John Innes Centre, UK*).** Transgenic rice for Africa with resistance to rice yellow mottle virus (RYMV) has been developed using the gene-silencing approach. These plants have performed very well under containment testing in growth cabinets. Plans are underway for testing in screenhouses in Africa and eventually to field-test them in Africa in approximately three years. Collaborating with WARDA. DFID funding.
- **Nematode resistance in upland and lowland rice (*Prof. H. Atkinson, University of Leeds, UK*).** In collaboration with IRRI and WARDA, this project aims to develop resistance to *Meloidogyne*, *Pratylenchus* and *Hirschmanniella* nematode species on upland and lowland rice varieties. DFID funded.
- **Resistance to bacterial blight (*Dr. S. Datta, IRRI*).** IRRI has developed transgenic rice resistant to the bacterial blight (BB) pathogen (*Xanthomonas oryzae, pv. oryzae*). Bacterial blight is one of the world's most destructive diseases of rice. A dominant gene for resistance to blight was transferred to the cultivated variety IR24 through conventional breeding from the wild species, *Oryza longistaminata*. The gene was then used to transform elite cultivated varieties. Field tests in China have shown promising levels of resistance to several races of the pathogen.
- **IMI™ Rice Seed (*American Cyanamid, New Jersey*).** American Cyanamid is cooperating with universities and public and private seed companies to develop rice varieties tolerant to imidazolinone herbicides. These are flexible, environmentally friendly herbicides that provide superior contact and residual control of weeds. Availability estimated to be within 6 years.

## Prospects

Rice biotechnology has benefited from enormous financial investment over recent years, and there are many important transgenic traits now in the testing phase.

However, it is not clear whether many local African rice varieties have been used in much of this work. Since the rice-growing environment in the ASARECA region is so diverse, it might be difficult to prioritize the major needs for research on this crop. Once such prioritization is done, it would seem that the possibilities of transferring beneficial traits (primarily herbicide resistance, virus resistance and fungal disease resistance) to local varieties would require comparatively low investment in order to capitalize on previous work.

# Cassava *(Manihot esculenta)*

## Background

The ASARECA network responsible for cassava is **EARRNET** (the Eastern Africa Root Crops Research Network). Cassava is a perennial shrub that produces a high yield of tuberous roots in 6 months to 3 years after planting. Originating in Central and South America, cassava spread rapidly throughout Africa after its arrival on the continent at the end of the sixteenth century.

Cassava provides a major source of calories for poor families because of its high starch content. With minimum maintenance, farmers can dig up the starchy root and eat it 6 months to 3 years after planting. Thus, people can cultivate cassava during times of war or natural disaster when no other food is available. In Africa, the leaves of the cassava are also eaten as a green vegetable, and provide a cheap and rich source of protein and vitamins A and B.

In Southeast Asia and Latin America, cassava has also taken on an economic role. Various industries use it as a binding agent, because it is an inexpensive source of starch. Cassava starch is used in the production of paper and textiles and as monosodium glutamate (MSG), an important flavoring agent in Asian cooking. In Africa, cassava is beginning to be used in partial substitution for wheat flour, providing income to resource-poor farmers and saving foreign exchange for national governments.

World production in 1995 was about 165.3 million tons from about 16.2 million ha. Currently, Nigeria, Brazil, the Democratic Republic of Congo, Thailand, and Indonesia are the world's largest producers of cassava. Thailand is the largest exporter, whereas Africa exports relatively little because production is almost entirely consumed locally as food.

Current sub-regional production in Eastern Africa is estimated to be approximately 28 million metric tons. Average yields are 10.5 t/ha. The relative importance of the crop varies among countries. The main producing countries in the region are the Democratic Republic of Congo, Uganda and Madagascar. Production in Kenya, Burundi and Rwanda is lower, but has increased over recent years as greater national attention was given to the crop. Most of the production increases have been due to an increase in the land area under cultivation rather than an increase in yield.

Cassava is grown mainly by subsistence farmers, for most of whom it is the primary staple. It is also used as a cash crop, and is processed to produce industrial starches, tapioca, and livestock feeds. Approximately 80% of cassava is processed into flour or cassava chips, with the remaining 20% consumed fresh. Although it is generally grown in mixed cropping systems with maize, peas, beans, sweet potato and sorghum/millet, cassava is replacing other food crops in the region. Farmers in

Uganda, Tanzania and Congo rate cassava as their most important crop, whereas maize is the crop of choice in Burundi and Kenya

The CGIAR research centers IITA and CIAT have a mandate for cassava research and have developed many elite varieties with improved qualities. IITA has discovered spontaneous polyploids in cassava that are characterized by enormous vigor and variation in form and structure. Selections from triploid "super cassava" have doubled the yields of existing improved varieties with normal chromosome numbers. IITA has also introduced to Africa a wider genetic base for cassava improvement, focusing on materials with resistance to mites, mealybugs and cassava bacterial blight; tolerance to drought; low cyanogen potential, and good cooking quality. IITA has assisted with identifying, evaluating and shipping natural enemies to control the major insect pests of cassava, the cassava mealybug and cassava green mite.

**EARRNET**'s technology development and transfer efforts fall into five categories: research and technology transfer, training, information exchange and institutional capacity building. Cassava production requires a supply of vegetative planting materials, the multiplication of which is low in comparison with grain crops, which are propagated by true seed. Cassava planting materials are bulky and highly perishable, and hence their production and distribution are expensive. Yield stability is highly dependent on the quality of planting materials, and cuttings with low vigor, pest infestation and/or disease often limit production.

Historically, cassava had few serious pests and diseases in Africa; however, as production intensified and exotic pests were introduced, the situation changed. The major cassava pests are relatively few compared to other crops, but can still reduce yields by over 50%. The most severe pests are the accidentally introduced exotic species that have no natural enemies.

The main biotic constraints to cassava production in the region include:

- cassava mosaic virus (CMV)
- cassava mealybug
- cassava green mite
- root knot nematodes

**EARRNET** is currently involved in biotechnology projects in collaboration with the IITA in Nigeria and Uganda, and the Cassava Biotechnology Network (CBN). These include rapid multiplication of disease-free cassava planting material, and characterization of germplasm using molecular markers.

### *Current biotechnology products and projects*

- **Starch-modified cassava (*Dr. Richard Visser, Wageningen Agricultural University, Wageningen, The Netherlands*).** Genetic modification of cassava for starch modification (content and composition). Increases possibilities for industrial uses of cassava. Field-testing planned in Indonesia in 2001/2
- **Cassava with improved post-harvest life (*Dr. Richard Visser, Wageningen Agricultural University*).** Prevention of post-harvest rotting of storage roots. Increases possibilities for industrial uses of cassava. Field testing planned by 2003.

- **Reduced-cyanide cassava (*Dr. Richard Sayre, Ohio State University, USA*).** Transgenic cassava with reduced cyanide toxicity. Reduced cyanogens in processed foods. Anticipate human health benefits due to reduced cyanide in cassava. Ready for field testing immediately.
- **ACMV resistance (*Dr. Johanna Puonti-Kaerlas, Institute for Plant Sciences, Switzerland*).** Increasing resistance to African cassava mosaic virus. Field application anticipated within 5-10 years.
- **Prolongation of leaf life (*Dr. Johanna Puonti-Kaerlas, Institute for Plant Sciences, Switzerland*).** Substantial yield losses are caused by frequent leaf harvesting in regions where leaves are used as vegetable. This project aims to increase leaf life and thus increase overall yields. Field application anticipated in 2-3 years.
- **Improvement of root protein content (*Dr. Johanna Puonti-Kaerlas, Institute for Plant Sciences, Switzerland*).** Aim is to increase nutritional quality of cassava roots by improving overall protein content. Estimates field testing within 2-3 years
- **Insect resistance (*Dr. Johanna Puonti-Kaerlas, Institute for Plant Sciences, Switzerland)*** To reduce yield loss due to insect pests. Estimates field testing within 2-3 years
- **Insect and disease resistance (*Dr. Martin Fregene, CIAT, Colombia*).** Prospecting for increased productivity: pest/disease resistance, and enhanced root quality genes from cultivated and wild cassava germplasm pools – specifically resistance to white fly, cassava mealybug, cassava green mite, cassava mosaic disease, cassava bacterial blight, cassava brown streak virus. Field testing anticipated within 5 years.
- **Post-harvest quality improvement (*Dr. Martin Fregene, CIAT, Colombia*).** Prospecting for increased productivity: pest/disease resistance, and enhanced root quality genes from cultivated and wild cassava germplasm pools – specifically root quality traits such as increased starch quality/quantity, reduced post-harvest deterioration, production of bioplastics (polyhydroxyalkanoates), and increased dry matter content. Field testing anticipated within 5 years.

### Prospects

Several groups worldwide are working on transformation of cassava with traits that are directly applicable to the ASARECA region. Although most of the major goals of genetic transformation in cassava (e.g., resistance to African cassava mosaic virus) are still a few years from field application, once achieved they will make a significant impact on cassava production in the region.

# Groundnut (*Arachis hypogaea Linnaeus*)

### Background

There is no ASARECA network specifically focused on groundnut, although this is identified as a priority crop by ASARECA. Groundnut (or peanut) is a legume with yellow sessile flowers and subterranean fruits. Native to South America, it spread throughout the New World as Spanish explorers discovered its versatility. Today, it is grown under a wide range of environmental conditions. The largest producers of groundnut are China and India, followed by sub-Saharan African countries and Central and South America. Most of the crop is produced where average rainfall is 600-1,200 mm and mean daily temperatures are above 20°C.

Groundnut is a valuable cash crop for millions of small-scale farmers in the semi-arid tropics. It generates employment on the farm and in marketing, transportation and processing. Throughout the world, farmers cultivate about 22.23 million hectares of groundnut (yielding 29.22 million tonnes of pods), of which 13.69 million hectares are in Asia (India 8 million ha; China 3.84 million ha), 7.39 million hectares in sub-Saharan Africa, and 0.7 million hectares in Central and South America. Seventy percent of global groundnut production is in the semi-arid tropics.

The main use of groundnut is as a source of edible oil, but the high oil and protein content also make it an important food crop. Groundnut is a valuable source of E, K and B vitamins (it is the richest plant source of thiamine, or $B_1$, and is also rich in niacin, which is low in cereals). Groundnut cake, formed after the oil is extracted, is a high-protein animal feed. The cake is also processed to make products such as biscuits (cookies) and baby foods. Groundnut is important not only for its dietary contributions but also for its use as a cash crop and income generator, its potential in meeting part of the global demand for vegetable oils, its secondary value as animal feed and fodder, and its contribution to the sustainability of mixed cropping systems.

The ideal growing conditions for groundnut are well-drained, light-colored, loose, friable, sandy loam soil; optimum moisture in the pod zone; and an optimum mean daily temperature of about 30°C. It can be grown either as a sole crop or in combination with other crops (using intercropping or mixed cropping). Constraints include:

*Biotic constraints:*

- Fungal diseases -- early leaf spot, late leaf spot, rust, and *Sclerotium rolfsi*
- Viral diseases -- bud necrosis virus, tomato spotted wilt virus, peanut stripe virus, and rosette virus
- Insect pests -- white grub

*Abiotic constraints:*

- drought
- low pH
- low temperature

These constraints occur in various combinations in Asia, Africa, and the Americas.

There is close research collaboration in Asia and Africa between the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the national programs and advanced research institutions. Development of high-yielding cultivars of desired duration having resistance/tolerance to single or multiple stresses and developing stress management strategies are the main objectives of groundnut improvement programs. At ICRISAT, a genetic resources program maintains 13,460 groundnut accessions including 197 wild *Arachis* species from 89 countries. The wild *Arachis* species are a reservoir of genes for high levels of resistance to various stresses.

Considerable progress has been made in conventional breeding for pest and disease resistance, and management strategies have been developed that include genetic resistance for rust, late and early leaf spots, aflatoxin, rosette virus, and peanut bud necrosis virus. However, the use of molecular markers and genetic transformation has yet to make much of an impact on groundnut research.

### *Current biotechnology products and projects*

- **Resistance to groundnut rosette virus (*Dr. Mike Deom, University of Georgia, USA*).** Control strategies for peanut viruses including transgenic resistance, natural resistance, and virus variability. Rosette virus occurs throughout Africa, where epidemics occur at about 5-7 year intervals and result in losses of up to 80% in those years.
- **Aflatoxin-free groundnuts (*Dr. Nancy Keller, Texas A&M University, USA*).** All existing peanuts can be contaminated by aflatoxin from infestation with *Aspergillus spp.* Aflatoxins are class A carcinogens and immune system suppressants, and can interact with hepatitis to effect a 60-fold increase in liver cancer rates of infected people. Most Africans have an aflatoxin burden. This project is using a genetic approach to eliminate aflatoxin contamination of groundnut by altering plant genes that effect either *Aspergillus* growth or aflatoxin gene regulation. Field trials are anticipated within 5-8 years.
- **Herbicide resistance (*Dr. Tim Williams, University of Georgia and Monsanto*).** A project is in the planning stages to develop herbicide resistant peanuts as a means of overcoming the labor costs of peanut production. Labor issues are likely to become a major issue given the HIV/AIDS epidemic in the continent.
- **High Oleic Peanut (*Mycogen/Dow AgroSciences, Indianapolis, USA*).** Peanut plants modified by mutagenesis to produce nuts high in oleic acid results in longer life for nuts, candy and peanut butter.
- **High beta-carotene peanuts (*Monsanto*).** Monsanto has developed technology to increase beta-carotene production in canola. This technology could be transferred to Africa for application to peanut.
- **Drought tolerance (*ARC-Grain Crops Institute, South Africa*).** Developing plant regeneration systems for groundnut, and systems for transformation of foreign genes into groundnut for drought resistance.

# Fruit and Vegetables

## Background

There is currently no ASARECA network primarily focused on fruit and vegetables. Fruit and vegetables have been major targets of biotechnology efforts over the last 10 years, and the list of products and projects given below is in no way comprehensive. The principal targets for transformation of fruit and vegetables initially have been quality traits, such as improved post-harvest life. Viral and fungal resistances are also now being incorporated into many commodities, and increasing effort is being put into nutritional traits, such as improved antioxidant and vitamin content. These products are expected to be commercially available within the next 5-10 years.

The first transgenic food product to go on sale (in the USA in 1994) was a genetically modified tomato, the FLAVR SAVR™ tomato produced by the U.S. company Calgene Inc. This genetic modification that slows the genes controlling the ripening processes in fruits and vegetables, which allows them to remain longer on the plant to develop their full flavor (and color). They also stay firm enough to be transported to the market. In addition to being more appealing to the consumer, the major advantage of the modified tomatoes is reduced losses in the harvest and marketing chain. The advantages of this technology are obvious for developing countries where post-harvest losses of fresh produce are often extremely high.

### *Current biotechnology products and projects*

- **Virus-resistant papaya (*Cornell University, USA and Pharmacia-UpJohn Co., USA*).** A new Hawaiian papaya, genetically resistant to papaya ringspot virus, is now widely grown as a result of collaboration between Cornell University, the University of Hawaii, and the Pharmacia-UpJohn Company. This new papaya variety's unique design will protect orchards from the significant yield decline experienced from ringspot infection.
- **FreshWorld Farms® Tomato (*DNAP Holding Corporation, Oakland, CA*)**. The FreshWorld Farms® tomato is a fresh market tomato developed through somaclonal variation to have superior color, taste and texture and a 10- to 14-day shelf life.
- **FreshWorld Farms Endless Summer® Tomato (*DNAP Holding Corporation*)**. The Endless Summer® tomato is a genetically engineered version of the FreshWorld Farms® tomato on the market since April 1993, and shares its improved color, taste and texture. It also has an extended shelf life of more than 30-40 days after harvest. Transwitch® technology was used to suppress production of ethylene, the hormone that causes fruits to ripen.
- **FreshWorld Farms® Sweet Mini-Peppers (*DNAP Holding Corporation*)**. The FreshWorld Farms® sweet mini-pepper has a novel sweet taste, deep red color and is nearly seedless. It was developed through anther culture, an advanced breeding technique that captures and stabilizes preferred characteristics such as taste, texture and low seed count.
- **FreshWorld Farms® Cherry Tomatoes (*DNAP Holding Corporation*)**. The FreshWorld Farms® cherry tomato is specially bred for superior taste, color and texture. It is sold through U.S. distributors and supermarket chains in the Mid-Atlantic, Northwest and Midwest regions.
- **Increased Pectin Tomatoes (*Zeneca Plant Sciences*)**. Tomatoes that have been genetically modified to remain firm longer and retain pectin during processing into tomato paste.
- **Genetically engineered fruits and vegetables with longer post-harvest shelf life (*Agritope, Inc, now Exelixis, San Francisco*)**. Using ethylene-control technology, Agritope, Inc., is creating delayed-ripening, longer-lasting tomatoes, raspberries and strawberries. (available in 6 years)
- **Virus-resistant tomatoes (*Monsanto / Calgene, LLC*)**. These tomato plants will be resistant to infection by certain plant viruses. Expected to become commercially available within 6 years.

- **Ripening-Controlled Cherry tTomatoes (*DNAP Holding Corporation*)**. Using the same technology as in its Endless Summer™ tomato, the company has developed cherry tomatoes with longer market life, improved flavor and better harvest traits through ripening control.
- **Firmer Peppers (*DNAP Holding Corporation*)**. This sweet pepper has been modified using Transwitch® technology to remain firmer after harvest. Pepper plants are currently in field evaluations.
- **Sweeter Peppers (*DNAP Holding Corporation*).** This pepper has been modified to be sweeter and tastier by over-expressing a gene for sweetness. Pepper plants are in early stages of seed increase and field evaluation.
- **Ripening-Controlled Bananas and Pineapples (*DNAP Holding Corporation*)**. Using the same ripening control technology as in its Endless Summer™ tomato, the company is developing banana and pineapple varieties with extended market life.
- **Strawberry (*DNAP Holding Corporation*).** Strawberries with improved market life have been developed by using Transwitch® technology to keep fruit firmer after harvest and also adding genes to resist disease.
- **Fresh Market Tomato (*Zeneca Plant Sciences*)**. Zeneca is modifying tomatoes for enhanced flavor, color and increased antioxidant vitamin content.
- **Insect Protected Tomato (*Calgene*)**. Tomato plants with insect resistance Bt genes. Available within 6 years.

# Animal health

## Background

There is no ASARECA network specifically for animal health issues, although other networks deal with animal production issues. The major network involving livestock is **A-AARNET** (the ASARECA Animal Agricultural Research Network). Livestock are crucial to most subsistence farmers in Africa, providing milk, eggs and wool; pulling plows; and fertilizing crops and soils. They often constitute a family's primary source of financial security. More productive livestock could provide farmers with the means to achieve greater economic security. There are several areas in which biotechnology is already benefiting animal production and health in the developed world, but there is so far little evidence of much impact in Africa.

One of the challenges for genetic improvement of livestock is to increase reproduction rates by improvement of reproductive physiology. This can be achieved using several techniques, including artificial insemination and embryo transfer/*in vitro* fertilization methodologies. Although artificial insemination is used widely in developed countries it is used far less in developing countries, with the exception of South Africa, and is generally associated with dairy cattle. The use of embryo technology can greatly increase livestock productivity, but this method is not economically feasible for commercial use on small farms at present.

However, the use of genetic markers for important traits is likely to be a very valuable technique in livestock breeding. Researchers have already identified genetic markers for resistance to environmental stress and some parasitic diseases -- e.g., tolerance to African trypanosomiasis in cattle, and resistance to endoparasites in Red Maasai sheep. Although there has recently been a great deal of publicity given to the cloning of and production of transgenic animals, these advances are more likely to make an impact in the area of basic research on the role of genes in the control of physiological processes than on animal productivity per se.

In sub-Saharan Africa three vector-borne diseases stand out as major barriers to improved livestock productivity: African trypanosomosis, East Coast fever and heartwater. They threaten tens of millions of cattle, sheep and goats and cost over $4 billion annually -- approximately one-quarter of the total value of livestock production. To meet demands from growing populations and rapid urbanization in developing countries, the necessary growth in livestock output will have to come in large part from improving the efficiency of regional production systems.

Biotechnology can address these disease problems in several ways, for example by providing methods for accurate diagnosis, and in the production of new more effective vaccines. The high sensitivity and specificity of DNA-based diagnostic tests now allow the accurate diagnosis and detection of many of these livestock diseases, some of which cannot easily be detected using other methods. A detailed review of such diagnostics is given in Bourne and Bostock (1992) and Robinson and McEvoy (1993).

In the field of livestock improvement, recombinant animal vaccines have considerable application in Africa in combating livestock diseases. Not only can such vaccines be produced inexpensively, but they also offer advantages of multiple protections, low costs, and distinction between vaccinated and naturally infected animals. This latter feature is highly desirable in Africa with respect to livestock export and in disease eradication campaigns. Vaccination offers a potentially more effective and sustainable method of disease control than other methods, such as chemotherapy and controlling insect vectors.

Research strategies for the development of better, cheaper vaccines are always being sought, and through the use of monoclonal antibodies and recombinant DNA technologies it is now possible to produce immunogenic components much more rapidly. These technologies are increasingly being used to clarify the pathogenic mechanism and immune responses to disease, and this will continue to lead to the production of more effective vaccines. Some of the recombinant vaccines already available are listed below, and a full list is given in Rege (1996).

Other advances in biotechnology that may improve productivity of livestock in developing countries include the use of recombinant bovine somatropin (BST) to improve milk production in cattle and the production of transgenic forage and feed crops with improved nutritional quality and digestibility. Disease diagnostics and vaccines are, however, the advances most likely to give the greatest impact in the relatively short-term.

The CGIAR center responsible for livestock is the International Livestock Research Institute (ILRI) in Kenya.

### *Current biotechnology products and projects*

- **Vaccine for heartwater (cowdriosis) for cattle (*Onderstepoort Veterinary Institute, South Africa*).**

- **Recombinant African horsesickness virus subunit vaccine (*Onderstepoort Veterinary Institute, South Africa*).**
- **Recombinant vaccine against bluetongue virus for sheep (*Onderstepoort Veterinary Institute, South Africa).***
- **Rotavirus vaccine** (***U.S. National Institutes of Health and Wyeth-Lederle Philadelphia***). In collaboration with the U.S. National Institutes of Health (NIH) and Wyeth-Lederle, USAID provided support for the clinical trials of a new rotavirus vaccine in Venezuela. The NIH and Wyeth-Lederle developed the vaccine and Wyeth provided the vaccine for clinical trials.
- **Rinderpest vaccine** (***University of California at Davis and Pan- African Rinderpest Campaign***). Implemented through the University of California at Davis, along with the Pan- African Rinderpest Campaign (PARC). This project has developed a heat-stable recombinant rinderpest vaccine for use on livestock and an inexpensive field rinderpest diagnostic kit.
- **Heartwater vaccine** (***University of Florida and Veterinary Service of Zimbabwe***). Implemented through the University of Florida in collaboration with the Veterinary Service of Zimbabwe. The project developed a recombinant vaccine against the ruminant disease *Cowdriosis* (heartwater) and will conduct small-scale field trials of the vaccine to determine efficacy and safety.

### Prospects

**A-AARNET** does not currently have a biotechnology unit. However, it uses tissue culture methods to produce plantlets for forage trials, and sees potential in the adaptation and use of other molecular tools such as thermostable vaccines, molecular markers for both livestock and forage crops, and artificial insemination methods. **A-AARNET** works closely with the International Livestock Research Institute (ILRI), which has extensive experience in livestock biotechnology.

# References Cited

**ASARECA Networks' Five-Year Plans.**

Bennetzen, J. L. (1995). "Biotechnology for sorghum improvement." **In** *African Crop-Science Journal (Uganda)* **3**(2)*: Special Issue on Sorghum Biotechnology,* pp. 161-170.

Bourne, J. and Bostock, C. (1992). "Disease Control." In A. D.Thelwall (Ed.), *Innovation in Agro-Biotechnology: Case Study on Animal Production.* Commission of the European Communities, pp. 71-83.

Brink, J. A., Woodward, B. R. and DaSilva, E. J. (1999). "Plant Biotechnology: a tool for development in Africa." *Electronic Journal of Biotechnology,* **1**(3). December 1999, Vol.1, no. 3. Available from: http://www.ejb.org/content/vol1/issue3/full/6/index.html. ISSN 0717-3458.

Carneiro, M. F. (1999). "Advances in coffee biotechnology." *AgBiotechNet* 1999 Volume **1** January, ABN 006. Available at http://www.agbiotechnet.com/reviews/JAN99/HTML/Carneiro.htm

Dale, J. L. (1999). "Banana Biotechnology: already a reality." *AgBiotechNet* 1999 Volume **1** November, ABN 033. Available at http://www.agbiotechnet.com/reviews/nov99/html/Dale.htm

IBS-ISNAR (1999). *Assessing the feasibility of a regional initiative on biotechnology for agricultural research in Eastern and Central Africa: A study commissioned by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA).*

Ives, C. L. and Bedford, B. M. (Eds.) (1998). *Agricultural Biotechnology in International Development*. Oxon, UK. CAB International. ISBN 0 85199 278 1 pp 354

Ives, C. L. and Wambugu, F. (2000). "Agricultural Biotechnology: Current and Future Trends and Implications for Africa, in T.S. Jayne, G. Argwings-Kodhek, and I. Minde (eds), Perspectives on Agricultural Transformation: A View from Africa, Nova Science, New York, 2001, forthcoming.

James, C. 2000. Global Status of Commercialized Transgenic Crops: 2000. ISAAA Briefs No. 21: Preview. ISAAA: Ithaca, NY.

Khush, G. S. and Bhar, D. S. (1998). "The application of biotechnology to rice." **In** Ives and Bedford, *Agricultural Biotechnology,* pp. 97-121.

Komen, J., Mignouna, J. and Webber, H. (2000). *Biotechnology in African Agricultural Research: Opportunities for Donor Organizations*. ISNAR Briefing Paper No. 43. The Hague: International Service for National Agricultural Research. Available at http://www.cgiar.org/isnar/publications/briefing/bp43.htm

Ndiritu, C. G. (1999). "Biotechnology in Africa: Why the controversy?" **In** *Agricultural Biotechnology and the Poor.* Washington, DC: The Consultative Group on International Agriculture, World Bank, pp. 109-134.

Ndiritu, C. G., and Wafula, J. (1998). "Agricultural Needs in Sub-Saharan Africa: The Role of Biotechnology." **In**: Ives and Bedford, *Agricultural Biotechnology in International Development* pp 49-60.

Powell, D. (1999). "Seminal paper on agricultural biotechnology: a summary of the science." Paper prepared for the Crop Protection Institute of Canada. (http://www.oac.uoguelph.ca/riskcomm/plant-ag/cpi/CPI-sept-99.htm)

Rege, J. E. O. (1996). "Biotechnology options for improving livestock production in developing countries, with special reference to sub-Saharan Africa." Addis Ababa, Ethiopia: International Livestock Centre for Africa (ILCA). http://www.fao.org/wairdocs/ilri/x5473b/x5473b05.htm

Robinson, J. J. and McEvoy, T. G. (1993). "Biotechnology – the possibilities." *Animal Production* **57**:335-352.

# Acknowledgements

In order to produce this report we have contacted many individuals and institutions in the agricultural development community including the CGIAR Centers, the private sector, universities and donor organizations. We are very grateful to all those who have responded to our requests for information. In particular, the authors would like to thank the Committee of Directors and the ASARECA Network Coordinators for their valuable input.

# Commodity Contacts

## Maize and Wheat

**CIMMYT**
International Maize and Wheat Improvement Center (CIMMYT)
Lisboa 27, Apartado Postal 6-641, 06600 Mexico, D.F., Mexico
Tel: (52-5) 726-9091
Fax: (52-5) 726-7559
http://www.cimmyt.mx)

**CIMMYT's Applied Biotechnology Center**
**Dr. David Hoisington**
Lisboa 27, Apartado Postal 6-641, 06600 Mexico, D.F., Mexico
Phone: (52-5) 726-9091 ext 1397
Fax: (52-5) 726-7558.
E-mail: d.hoisington@cgiar.org
http://www.cimmyt.cgiar.org/research/ABC/Index.htm

**The Asian Maize Biotechnology Network (AMBIONET)**
http://www.cimmyt.cgiar.org/ambionet/

## Potato

**Dr.  Marc Ghislain**
International Potato Center (CIP)
Avenida La Universidad 795, La Molina, P.O. Box 1558, Lima 12, Peru
Phone: (51-1) 349-6017/5783 or (1) 650-833-3365 (USA toll)
Fax: (51-1) 349-5638
E-mail: m.ghislain@cgiar.org or cip@cgiar.org
http://www.cipotato.org/

**Dr. David Douches**
486 Plant and Soil Science Building, Michigan State University, East Lansing MI 48824
Phone:  (517) 355-6887
E-mail:  douchesd@msu.edu
Web:  http://www.msu.edu/~douchesd/

**Dr. Dapeng Zhang**
Sweet potato breeder/geneticist
International Potato Center (CIP), PO. Box 1558, Lima, Peru
Tel: 51-1-3496017
Fax: 51-13495638

**Dr. Aziz Lagnaoui**
Potato IPM Project Leader
International Potato Center  (CIP: Centro Internacional de la Papa)
Apartado 1558, Lima 12, Peru
Phone:  (51-1) 349-6017
Fax:  (51-1) 349-5638
E-mail: a.lagnaoui@cgiar.org

## Rice

**Riceweb**
http://www.cgiar.org/irri/Riceweb/index.htm

**West Africa Rice Development Association (WARDA), Cote d'Ivoire**
Centro Internacional Agricultura Tropical (CIAT), Colombia.

**INTERNATIONAL RICE RESEARCH INSTITUTE**
MCPO Box 3127, Makati City 1271, Philippines
Phone:  (63-2) 845-0563, 845-0569
Fax:  (63-2) 845-0606
E-mail:  irri@cgiar.org

**The Asian Rice Biotechnology Network (ARBN)**
http://www.cgiar.org/irri/ARBN/arbnindex.htm

**Dr. M. L. Koyama**
Cereals Dept., John Innes Centre
Norwich Research Park, Norwich, Norfolk, NR4 7UH. United Kingdom
Phone:  +44 (0)1603 452 571 x2592
Fax:  +44 (0)1603 502 241
E-mail:  miki.koyama@bbsrc.ac.

**West Africa Rice Development Association (WARDA)**
Headquarters address: 01 B.P. 2551, Bouaké, Côte d'Ivoire
Director General: Kanayo F. Nwanze.
Email: k.nwanze@cgiar.org
Information Officer: Guy Manners.
E-mail:  g.manners@cgiar.org

Fax: (225) 634714

**Centro Internacional de Agricultura Tropical (CIAT)**
Headquarters address: Apartado Aereo 6713 Cali, Colombia
Director General: Grant M. Scobie
E-mail: g.scobie@cgiar.org
Information Officer: Nathan Russell
E-mail: n.russell@cgiar.org
Fax: (572) 4450-273

**Other Internet sites for rice**
http://www.cgiar.org/irri/Riceweb/research/Res_ntbio.htm
http://www.riceworld.org/
http://www.cgiar.org/irri/

## Cassava

**Dr. Willy Roca**
CIAT, Apartado Aéreo 6713, Recta Cali-Palmira, Km 17, Cali, Colombia.
Phone: 1 650 833 6625
E-mail: w.roca@cgiar.org

**Dr. Claude Fauquet**
ILTAB/Donald Danforth Plant Science Center
8001 Natural Bridge Road, Molecular Electronics Building, Room 307, St. Louis, MO 63121
Phone: 314-516-4581
Fax: 314-516-4582
E-mail: info@danforthcenter.org

**Dr. Johanna Puonti-Kaerlas**
Cassava Group Leader
Institute Of Plant Sciences, Institute: Eth-Zurich
Universitatstr. 2, Eth-Zentrum/Lfw E 17, Ch-8092 Zurich, Switzerland.
Phone: 41-1-6322244 (Of) 6323818 (Lab)
Fax: 41-1-6321044
E-Mail: Johanna.Puonti-Kaerlas@Ipw.Biol.Ethz.Ch

**Dr. Richard G.F. Visser**
Department Of Plant Breeding, Wageningen Agricultural University
PO Box 386, Lawickse Allee 166 , 6700 Aj, Wageningen, Netherlands
Phone: 31-317-482836/489111
Fax: 31-317-483457
E-Mail: Richard.Visser@Users.Pv.Wau.Nl

**Dr. Richard T. Sayre**
Department Of Plant Biology/Biochemistry, Ohio State University, 2021 Coffey Rd. 310f
Kottman Hall, Columbus, Ohio 43210-1293, U.S.A.
Phone: 1-614-292-9030/8379
Fax: 1-614-292 7162
E-Mail: sayre.2@osu.edu

**Dr. Martin Fregene**
CIAT, Km 17Cali-Plamira Recta, AA6713, Cali, Colombia
Phone: 57-2-4450000 (Colombia); 1-650-833 6625 (USA direct)
Fax: 57-2-4450073 (Colombia); 1-650-833 6626 (USA direct)
E-Mail: M.Fregene@cgiar.org

## Sorghum/Millet

**Dr. N Seetharama**
Sr. Scientist: Cellular and Molecular Biology, ICRISAT P.O., Patancheru AP 502324, India
Phone: +91 -(40) - 3296161 Ext. 2383 (office)
Fax: +91-40-3241239
Direct phone: +91-8455-8 2383
E-mail: N.Seetharama@cgiar.org
http:/www.cgiar.org/icrisat

**Dr. John Yohe**
INTSORMIL (Sorghum and Millet) CRSP, University of Nebraska
113 Biochemistry Hall, Lincoln NE 68583-0748
Phone: 402-472-6032
Fax: 402-472-7978
E-mail: jyohe@unl.edu

## Banana

**International Network for the Improvement of Banana and Plantain (INIBAP)**
Parc Scientifique Agropolis II, 34397 Montpellier Cedex 5, France
Phone: (33) 467 61 1302
Fax: (33) 467 61 0334
E-mail: inibap@cgiar.org
http://www.cgiar.org/ipgri/inibap/index.htm

**Promusa (a Global Program for *Musa* Improvement)**
http://www.inibap.fr/promusa/

**Dr. Laszlo Sagi and Dr. Rony Swennen**
Laboratory of Tropical Crop Improvement, Catholic University of Leuven
Kardinaal Mercierlaan 92, B-3001 Heverlee, Belgium
Fax: +32-16-321993
E-mail: laszlo.sagi@agr.kuleuven.ac.be
http://www.agr.kuleuven.ac.be/dtp/tro/home.htm

## Groundnut

**Dr. Mike Deom**
University of Georgia, Miller Plant Sciences, Athens GA 30602-7274
Phone: (706) 542-1270
E-mail: deom@uga.cc.uga.edu

**Dr. Nancy Keller**
Dept of Plant Pathology and Microbiology
Room 120, Peterson Bldg., Texas A&M, College Station, TX 77843-2132.
Phone: (409) 845-7311
E-mail: n-keller@tamu.edu

**Dr. Tim Williams**
Peanut CRSP, University of Georgia
Georgia Ag Experiment Station, 1109 Experiment St, Griffin GA 30223-1797 USA
Phone: 770-228-7312
Fax: 770-229-3337
E-mail: crspgrf@gaes.griffin.peachnet.edu or twillia@gaes.griffin.peachnet.edu

## Bean/Cowpea

**Dr. Irvin Widders**
Bean/Cowpea CRSP
A436 Plant and Soil Science Building, Michigan State University, MI 48824-1035 USA
Phone: 517-353-5480
E-mail: widders@pilot.msu.edu